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TIMEPAC PROJECT

MASTER'S THESIS

Enhancing EPC schemas through operational data integration

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"I am thankful to my Creator for guiding me throughout this work at every step and for every new thought that You set up in my mind to improve it. Indeed, I could have done nothing without Your priceless help and guidance. Whosoever helped me throughout my thesis, whether my parents or any other individual was Your will, so indeed none be worthy of praise but You.

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"Dedicated to my exceptional parents and adored siblings whose tremendous support and cooperation led me to this wonderful accomplishment."

Abstract

EPCs (Energy Performance Certificates) are important tools to identify the performance of a building. In many countries, it is compulsory to have EPCs while selling, renting, constructing, or renovating a building or a part of it. This research thesis under the shelter of the H2020 TIMEPAC project aims to broaden the array of the energy performance indicators within the Energy Performance Certificate. It aims to underscore a holistic approach to assessing the building's overall performance. There are several phases such as generation, storage, analysis, and exploitation that are included in the EPC workflow. This research thesis aims to perform an energy audit in a residential building in Torino with possibilities to implement energy efficiency measures for the upgrade of energy classification in Energy Performance Certificates. The expected outcomes of the research work can be IEQ (Indoor Environmental Quality) Assessment, BACS (Building Automation and Control) Assessment, TEPA (Tailored Energy Performance Assessment), and ECM (Economic Evaluation of Energy Efficiency Measures). The data obtained from the model simulated on a commercial software tool (Edilclima) will be calibrated with the measured data every week. The outcomes are expected to be stored in the database of TIMEPAC and later analyzed to define the problems, risk factors, and obstacles in the way of Energy Performance Certificates. Also, the standards specify the limits of calibrating on an hourly or yearly basis, but this thesis aims to find if these limits can be used weekly or not. This project is currently underway in Turin, Italy, in collaboration with TIMEPAC. Italian standards will serve as the foundation for the structuring and verification of the project.

The improvement of the EPCs is an iterative process that will keep on improving with the collection and analysis of more data from different regions.

Key Words: *Net Zero Energy Buildings, Energy Efficiency Measures, Energy Performance Certificates, Energy Audit, IEQ (Indoor Environmental Quality) Assessment, BACS (Building Automation and Control System) Assessment, TEPA (Tailored Energy Performance Assessment), and ECM (Economic Evaluation of Energy Efficiency Measures)*

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1 CHAPTER 1: INTRODUCTION

The buildings sector includes the energy used for construction, cooling, lighting, heating, appliances, and equipment accounting for one-third of the global energy consumption and emissions. As the world is advancing from a rural lifestyle to an urban lifestyle, businesses, and capital have been shifted to the building industry. The whole lifecycle from the production of raw materials to construction to refurbishment (major/minor) is majorly towards global climate change. As in developing countries, the global floor area is growing rapidly, and along with-it use of appliances increased too. To consider the future demand and emissions, the right decisions should be made for construction, services, appliances, and design. There are certain advancements in the techniques and design for the buildings to make it NZEB (Nearly Zero Energy building). It is the zero-emission building that has a very high performance with very low amount of energy required that is fulfilled by the renewable sources or zero carbon onsite production.

This work is the description of research on the existing residential building in Torino where the refurbishment techniques will be applied to enhance the energy performance. While working on the renovation of the building, it is very important to consider the occupant's comfort according to the legislation. Secondly, it is salient to improve the energy classification of the building by using the active and passive energy efficiency measures. All these steps are monitored under the financial analysis to check whether the investment is beneficial in terms of energy and economics. Energy design is a growing tendency that has different benefits for the community, an environmental one by reducing the pollutants, a global one by creating awareness, and an economical one by reducing the expenses costs for occupants.

Before proceeding toward the results, multiple topics need to be explained to complement the work of the thesis. The subtopics are related to the climate change, state of art EPCs and TIMEPAC project aims and previous projects. It is important to discuss the TIMEPAC projects aims and conclusions, as we are following its protocols. These all topics are interlinked and aid towards the thesis work.

1.1 GLOBAL CLIMATE CHANGE

The global climate change is the long-term shifts in temperature and weather patterns due to natural events or human activities such as burning of the fossil fuels like coal, oil, and gas. There are different GHGs (greenhouse gases) such as VOCs (Volatile organic compounds), carbon dioxide, and methane that are produced by multiple processes. There is also the production of aerosol particles that are under 10 micrometres which causes multiple diseases in humans. Clearing the land and cutting down the forests also causes the release of carbon dioxide. Global warming has been one of the most important issues for the last few decades due to excessive urbanization and carbon dioxide emissions. Figure 1 illustrates about how the temperature rose with the time indicating the global climate change. It is evitable that there is an increase of more than +1.2 ˚C till the span of 2022 which shows how world is facing the problem of global warming. In Pakistan, last year there was glacier outburst flooding that has caused economic and social problems. "The glaciers are melting in Pakistan due to variations in climate and causing global warming" (Rehman, Ma et al. 2021). Due to high increase in the temperature, there are the events of glacier lake outburst flooding that caused several deaths in the rural and urban areas. " Pakistan is experiencing a significant increase in temperature, but almost no change in precipitation, which has made temperature the dominating factor for defining droughts in recent years."(Ahmed, Shahid et al. 2018). There are also areas like Cholistan in Pakistan that is experiencing high levels of drought due to the climate change. The amount of rain is very few which causes the scarcity of water in the region. Due to increase in the temperature, there is more need of energy required for cooling as the set point temperature cannot be compromised due to comfort hence also the CO_2 emissions will increase. "Energy consumption and CO_2 emissions will reach their peak in the next 10 years."(Yuan, Xu et al. 2014). "The increase in the temperature is predicted as 1 to 3.7 degrees Celsius depending

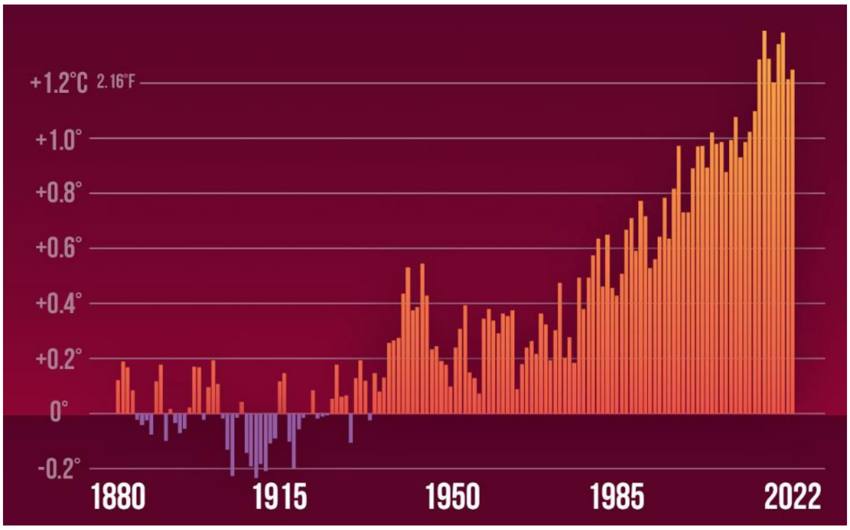


Figure 1 Rise of temperature due to climate change (Group 2023)

upon future greenhouse gas emissions" (Anderson, Hawkins et al. 2016). CO_2 and volatile organic compounds emissions are one of the most important issue world is facing right now. The building industry itself is a high contributor of emissions. "Out of these CO_2 emissions, 5-7% emissions of CO_2 are caused by the cement industry" (Benhelal, Zahedi et al. 2013). It is highly required to change the strategies and production mechanisms to limit the GHGs emissions that can only be done by the sustainable production, design, and construction of building, materials and building elements. "The results imply that carbon emissions can be reduced at the cost of economic growth or energy efficient technologies should be encouraged to enhance domestic production with the help of the financial sector and import environment-friendly technology from advanced countries" (Shahbaz, Hye et al. 2013). The problem of global warming is not related to only one country but to the whole world, we require the trade and support between the countries in order to decrease the emissions as less as possible. "The possible actions toward global warming are summed by three strategies: the no action, the mitigation, and the adaptation strategy" (Al-Ghussain 2018). "These strategies are implemented by the countries according to the agreements. Increased temperatures, and the associated heat stresses, are already expected to negatively impact crop yields in the regions" (Ault 2020). If the issue of global warming is not taken seriously then there can be many negative circumstances which include life risks, natural disasters, extinction, low productivity, and a high carbon footprint.

1.2 STATE OF ART FOR EPCs

Energy Performance Certificates (EPCs), an integral part of the Energy Performance of Buildings Directive 2002/91/EC1; 2010/31/EU2 , are an important instrument to enhance the energy performance of buildings (THE, 2002). The European commission has targeted the renovation policies that will account for 46% of the energy savings from the time span of 2021-2030. The EPCs are an integral part of EPBD, and they are contributing towards the enhancement of energy performance.

Different countries in Europe have different policies towards the EPCs. In the following paragraph, some of countries' approach towards the EPCs are mentioned. "In Portugal, they started a program in 2007 to rate the energy efficiency of buildings, and they've rated over 555,000 buildings by 2012. Since 2009, they've been rating about 2,500 new buildings and

9,000 existing buildings every month. In Greece, they've issued about 245,000 energy performance certificates, and around 13% of these are for non-residential buildings. Italy started rating buildings for their energy efficiency in 2005, covering all types of buildings." (BPIE, 2014). The above examples define some of the progress of the countries related to the EPCs, it can be seen that EU is involved in increasing the EPCs with high trend. In EU, they have a law that requires all buildings, whether they're for rent, sale, or public use, to be certified for their energy efficiency. Now, when it comes to measuring energy performance, different countries use different methods. Some use a scale from A to G to rate energy performance, but you can't directly compare a sports building with a D rating in one country to a D-rated sports building in another country. They might be very different in terms of energy efficiency even if they have the same rating.

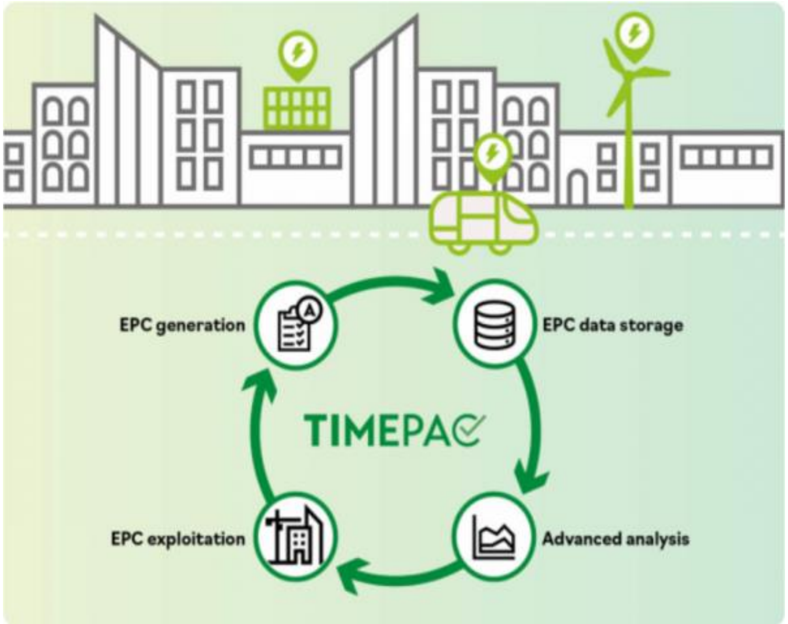


Figure 2 TIMEPAC methodology for TDS 2 (TIMEPAC 2020a)

There are several issues that are related to EPCs such as in several countries, the EPCs are just seen as a mandatory document to be prepared for several actions with no purpose other than the bureaucratic one. Another problem is also related to the proper knowledge of EPCs that is not conveyed completely to the auditors and the occupants. It is compulsory to have a complete understanding of the EPCs. It has not been properly studied by researchers or policymakers even if it is one of the important tools that encourages the building owners to perform building activities. Due to the scarce research that only focuses on the EPCs, more information is required to identify the weakness, problems, and improvements of EPCs (Gonzalez-Caceres, 2020). EPCs have a record of high errors as analyzed by A. Hardy et.al that "We find that 27% of EPCs in the open EPC record display at least one flag to suggests it is incorrect and estimate the true error rate of the EPC record to be between 36 and 62%" (Hardy, 2019). There could be multiple reasons behind the errors in EPCs such as EPC assessors disagreeing on floor type or other etc. There is a criticism for the EPCs that they don’t provide the information that is actual or real energy usage of the building. The only way to solve this is to use the correct value. There are some EPCs where they use words like assumed that shouldn’t be used. By making EPCs better for government, easier for occupants and adjusting them to the policies, we can make a strong tool to fight climate change (Reed, 2021) .

1.3 TIMEPAC PROJECT

This research thesis is under the TIMEPAC project which acronym for Towards Innovative Methods for Energy Performance Assessment and Certification of Buildings. It is a Horizon 2020 research project that aims to turn goals into action by transforming the EPC process. TIMEPAC aims to improve the existing certification process across multiple countries through the TDS approach which is the Transversal Deployment Scenarios. Figure 2 shows the EPC workflow from generation to exploitation involving multiple stakeholders and resources. TIMEPAC approach will consider:

- **Generating enhanced EPCs with BIM data** (Guidelines will be created for the EPC generation with building information modelling)
- **Enhancement of EPC schemas through operational data integration** (Goal of this research thesis)
- **Creation of the building renovation passports from data repositories** (The procedures will be made to trace the evolution of building refurbishment using different sources such as BIM)
- **Integrating smart readiness indicators and sustainability indicators in** EPC (Creation of a methodology for SRI and environmental sustainability indicators integration in the existing EPC schemes)
- **Large-scale statistical analysis of EPC databases** (Development of a large-scale analysis methodology to determine the energy balance of the building stock, energy refurbishment scenarios, and data quality checking of the EPC databases)

Other than the above approaches, TIMEPAC is developing an academy for training the auditors about the improvement tools in the EPC. In TIMEPAC, TDS will be validated in four demonstration scenarios which are improvement of certification with enhanced EPCs, building renovation scenarios from the analysis of enhanced EPC data, EPC exploitation through advanced analysis, and improvement of building operation with enhanced EPC across six European countries (Austria, Croatia, Cyprus, Italy, Slovenia, and Spain). The building under the focus of this research project lies in this category.

1.4 BUILDING'S SHARE FOR CARBON PRODUCTION AND CYCLE

"As the global population is expected to increase to 9.3 billion by 2050, the construction of new buildings and infrastructure will account for 35-60% of the remaining carbon budget" (Muller, Liu et al. 2013). "The construction sector accounts for about half of the total steel production where energy demand can be decreased by 60 to 95% by using secondary rather than primary raw materials" (UNEP 2013). "The systems of the buildings account for 30% of the global final energy consumption and 26% of global energy-related emissions" (IEA 2023a). There is a lifecycle of the buildings that is from production to construction to use to end of service. In each of the stage, there are energy costs associated as shown in Figure 3. These all stages have different types of emissions and VOC production.

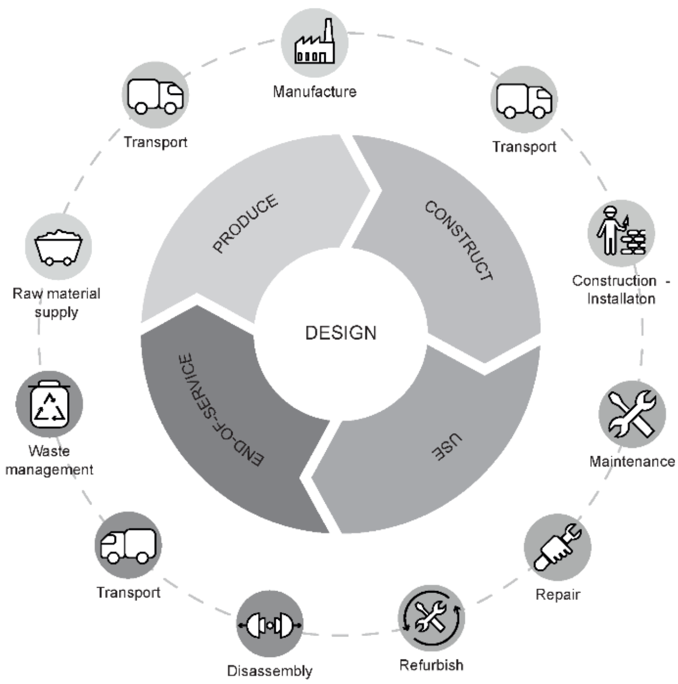


Figure 3 Life cycle of buildings (Delf 2016)

“The main contribution of carbon dioxide emissions is by the construction sector which accounts for 38% in 2019 out of which 28% is for buildings and 10% is for the construction material industry” (Alliance, and et al. 2020). The total emission from the construction sector is 10 billion tons of CO_2e (the number of metric tons of CO_2 emissions with the same global warming potential as one metric ton of another greenhouse gas). The concept of vertical, sustainable buildings is being implemented all over the world to counter global warming problems and address the issue of utilizing the population. With time, minimum performance standards and energy codes are increasing across the countries. The use of renewable energies in buildings to meet energy demands is increasing due to subsidies. The United Nations Biodiversity Conference, known as COP15, is the fifteenth gathering of countries that are part of the Convention on Biological Diversity (CBD). The main goal of this conference is to have these countries agree on specific targets and actions to protect and preserve various species and prevent the decline of ecosystems worldwide. In other words, it's a meeting where countries come together to discuss and plan how to safeguard the environment and the different forms of life on Earth. The 6 key messages for the COP 15 are as follows (SBCI 2009) :

1. The building sector can be the most potential sector for GHG reduction.
2. Countries cannot meet the emission targets by avoiding the energy gains in the building sector.
3. There are policies and technologies for the deep cuts in buildings GHG emissions.
4. The building industry is committed to working for the reduction of GHG emissions in many countries.
5. Significant co-benefits including employment will be created by policies that encourage energy-efficient and low-emission building activity.
6. Countries that fail to encourage energy efficiency and low carbon will lock countries into the disadvantages of poor-performing buildings for decades.

The building sector is also responsible for production of the non-CO_2 GHG emissions such as halocarbons because of the refrigeration used in the buildings and insulation materials. The Figure 4 shows the increase in the use of electricity consumption in OECD and non-OECD areas. OECD stands for Organisation for Economic Cooperation and Development.

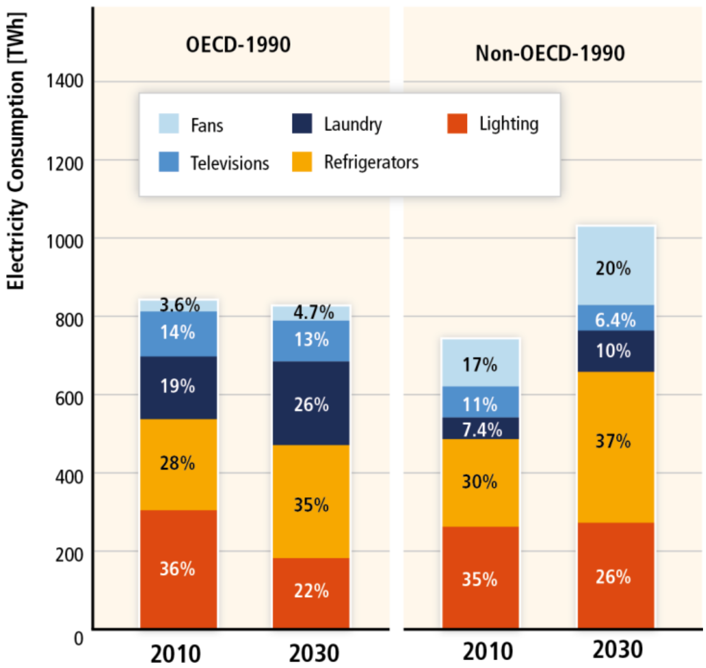


Figure 4 Rise in electricity consumption in OECD and Non-OECD countries (Change 2023)

While assessing the emissions through a life cycle approach, a significant amount of greenhouse gases is also generated by construction materials such as insulation, cooling systems, etc. The energy consumed in different activities as shown in Table 1:

Table 1 Types of energy involved in different activities (Swift, 2015) .

Energy	**Percentage %**
Energy embodied in construction	6
Energy for demolition	3
Energy embodied in structural materials	6
Energy embodied in skin (including replacement)	13
Energy embodied in services	10
Energy embodied in space fit-out	12
Energy embodied in operation	50

Table 1 defines that most of the energy is used in the operations in the buildings. So, in order to decrease the energy, we need to focus more on the systems that are used in the building and also the design so that less energy is consumed. The half of the energy is consumed by the operations in buildings. The least amount of energy consumed is in the demolition of the building.

1.5 EUROPEON APPROACH TOWARDS ENERGY PERFORMANCE

The energy performance of a building is connected to how energy-efficient it is. “Energy performance is the calculated or metered amount of energy needed to meet the energy demand associated with a typical use of the building, which includes, inter alia, energy used for heating, cooling, ventilation, hot water, lighting and technical building systems” (UNION, 2021) . When we talk about improving the energy performance of a building, it means finding ways to use less energy while still making sure the people inside the building are having the comfort required. To calculate the overall energy performance of the buildings, it is important to consider the appliances, building location, layout, and stratigraphy. The European Parliament's position for EPBD is:

- All the new buildings will have zero emissions by 2028.
- The existing buildings have to comply with standards to reach climate neutrality by 2050
- Residential buildings will have the following classification: Class E by 2030 and Class D by 2033
- Non-residential buildings will have the following classification: Class E by 2027 and Class D by 2030
- Member States will have to set higher standards for those buildings after that date and for the rest of the stock.

The key point of the EPBD recast (P9_TA(2023)0068, Amendments adopted by 14 March, 2023) Article 1 includes (Parliament 2023):

- The common general framework for a methodology for calculating the integrated energy performance of buildings and building units;

- The application of minimum requirements to the energy performance of new buildings and new building units;
- The application of minimum requirements to the energy performance of:
- Existing buildings and building units that are subject to major renovation;
- Building elements that form part of the building envelope and that have a significant impact on the energy performance of the building envelope when they are retrofitted or replaced;
- Technical building systems whenever they are installed, replaced or upgraded.
- The application of minimum energy performance standards to existing buildings and existing building units, in accordance with Articles 3 and 9;
- Harmonized framework for assessing the life-cycle global warming potential;
- Solar energy in buildings;
- The phasing out of fossil fuel use in buildings;
- Building renovation passports;
- National building renovation plans;
- Sustainable mobility infrastructure in and adjacent to buildings; and
- Smart buildings;

There are many reasons why building energy efficiency is important. By making more energy-efficient decisions, we can:

1. Decrease the demand for fossil fuel consumption
2. Improve the EPC with high indoor comfort
3. Improve energy security by reducing our reliance on imported energy.
4. Reduce the overall load so that we don’t require the expensive unit at peak point
5. Make buildings more affordable to operate, which would lower costs for the end user.
6. Have a high resale value of the building
7. Mitigate the climate change and global emissions

1.6 TECHNICAL BUILDING SYSTEMS

The buildings residential or non-residential use multiple systems for services such as heating, cooling, DHW, and ventilation to provide comfort to the tenant. These include HVACs and BACSs (Building Automation and Control Systems) that aid in highly efficient systems. Nowadays, buildings are equipped with smart systems that decrease energy consumption by using sensors and actuators. There are different types of HVACs used in buildings according to the demand and availability of systems. In the following pages, the systems of the buildings will be explained. The energy flow in the building is comprised of the generation, storage, distribution, control, and emissions subsystems. Figure 5 shows the subsystems related to the heating, primary energy enters the building and there are losses at each subsystem. There is an input of electricity at each subsystem. The efficiency of each subsystem is calculated by the ratio of thermal energy output from the subsystem to the thermal energy input to the subsystem. The $Q_{H,nd}$ is calculated by considering the losses and thermal energy inputs.

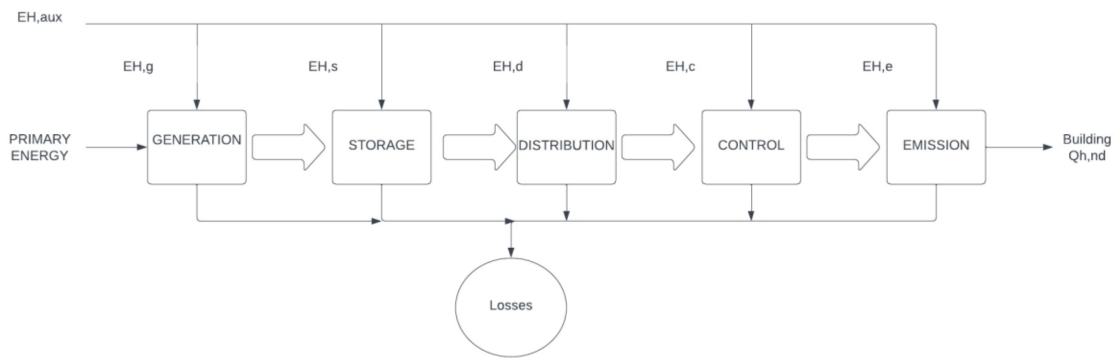


Figure 5 Energy flows

1.6.1 HEATING

The space heating process is primarily achieved by different emitters deploying multiple phenomena like free convection (radiators, electric heaters), forced convection (fan coils), and radiation heat transfer (radiators). Building heating systems are used for increasing the temperature of the space. The heating systems control the indoor air temperature in cold weather to provide thermal comfort to the occupants according to the standards. The fuel types and generation method of heating varies according to the development level and weather of the countries but generally, natural gas and electricity are the main secondary furl. The heating systems are designed according to the heating losses of the building. The types of heat losses are conduction, convection, and air leakage. The conduction and convection losses occur from the components of the building such as windows, walls, etc. It can be calculated as follows:

$$\dot{Q}_{\text{loss}} = AU\Delta T$$

...............................Eq 1

Where,

$\dot{Q}_{\text{loss}}$ = Heat transfer from indoor to outdoor (W)

A = The surface area of the building in meters (m^2)

U = Thermal transmittance (W/m^2K)

ΔT = Temperature difference between the indoor to outdoor (°C)

U can be calculated by,

$$\frac{1}{U} = \frac{1}{h_{in}} + \frac{x_1}{U_1} + \cdots + \frac{x_n}{U_n} + \frac{1}{h_{out}}$$

...............................Eq 2

Where,

h_{in} and h_{out} = Heat conduction coefficients between the surface of building material and surrounding air (W/mK)

$x_1, x_2, \ldots, x_n$= Thickness of material (m)

$k_1, k_2, \ldots, k_n$ = Heat conduction coefficients of the materials (W/mK)

Figure 6 shows the mechanism of the heat losses through the building.

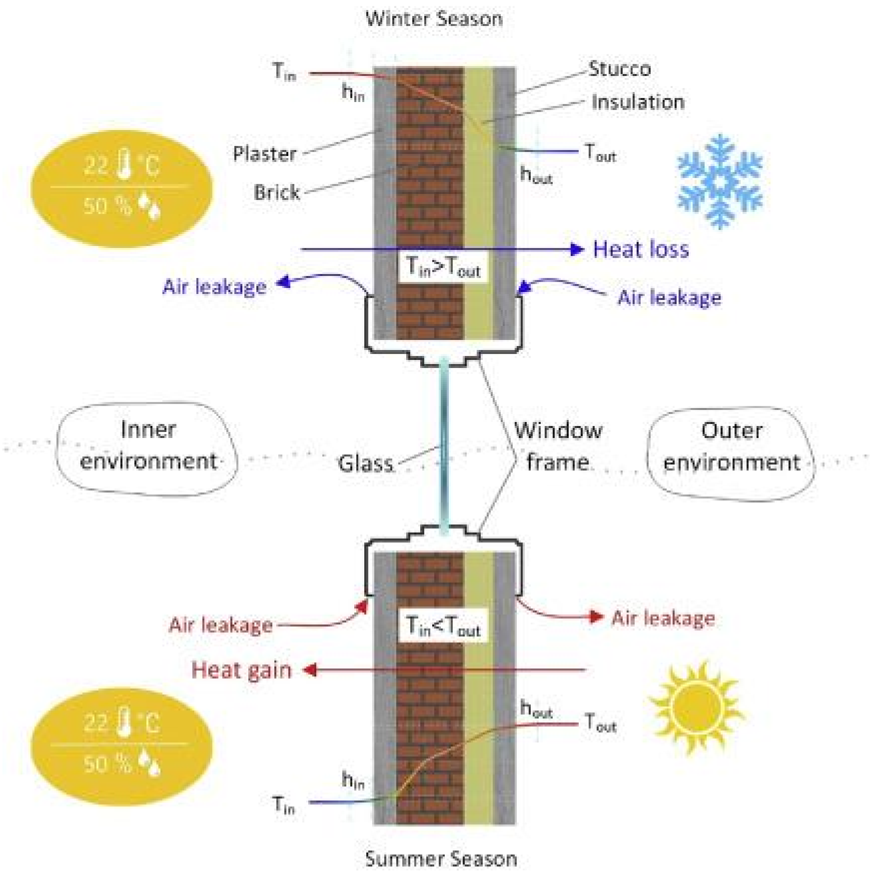


Figure 6 Thermal transmittance during summer and winter seasons (Dincer and Erdemir 2021)

While leakages from window and door openings are calculated as follows (Dincer, 2021):

$$Q^{\cdot}_{leak} = \left(\frac{1}{3.6}\right)(a * L)R * H * \Delta T * Z_e$$

...............................Eq 3

Where,

$Q^{\cdot}_{leak}$ = heat loss due to air leakage (W)

a = Coefficient of leakage (m^3*Pa/h ˚C)

L = length of the door (m)

R = Wind permeability coefficient (-)

H = Effective wind coefficient (-)

ΔT = Temperature difference between the indoor and outdoor (˚C)

Z_e = Coefficient of corner opening (-)

There are several methods to decrease energy consumption such as using heat pumps. The results of the research have proved that heat pumps increase primary energy savings, if compared to traditional solutions, and are a viable solution (Roccatello, Prada et al. 2021).

1.6.2 COOLING

Cooling systems in the buildings aim to decrease the temperature of the building during the summer days or when there are significant thermal gains (internal and solar gains). The cooling of the building is divided into two types such as passive cooling and active cooling. Passive cooling is natural cooling such as a natural ventilation in the buildings. Active cooling uses fuel or a heat source to provide the cooling and can deploy the following technologies and strategies:

- Earth-to-air heat exchanger
- Open or closed loop water to the air heat exchanger
- Mechanical, or forced ventilation.
- Chilled water
- Refrigerants
- Evaporative cooling
- Ice

Cooling is important because 2 billion air-conditioning units are working right now in the world of which 70% is the residential units (IEA, 2023b). This accounts for the high use of fuel all over the world. As the world is warming day by day, cooling is demanded more. Over the next three decades, the use of air conditioners is set to soar, becoming one of the top drivers of global electricity demand (IEA, 2023b). The building design should be effective, and the systems should be effective to have less primary energy consumption. We should also change the behaviour of using cooling systems and set the set points to 24-25 degrees Celsius to save energy (IEA, 2023b).

1.6.3 VENTILATION

Ventilation is the process in which the air is introduced or extracted from space to regulate the contaminants and provide indoor environmental comfort. There are two types of ventilation as forced or natural ventilation. Forced ventilation is done by using the mechanical components such as fans etc. while the natural ventilation is done through openings and windows etc. The issue in the building arises from the gaps and cracks in the building that causes uncontrolled airflow which leads to temperature fluctuations, undermining desired comfort level. Natural ventilation harnesses wind and temperature differentials to create airflow, offering cost-effective advantages compared to mechanical systems in terms of operational and maintenance costs. It requires no maintenance and has less precise control of the ventilation rates. It may also cause the risks due to extreme weather conditions. Larger openings are needed on upper floors to achieve equal airflow due to smaller pressure differences, while lower floors can have smaller openings for the same effect. There are different types of ventilation systems in the building such as the following (H.B.AWBI, 2003)

- Local exhaust ventilation (Figure 7)
- Piston ventilation (Figure 8)
- Displacement ventilation (Figure 9)
- Mixing ventilation

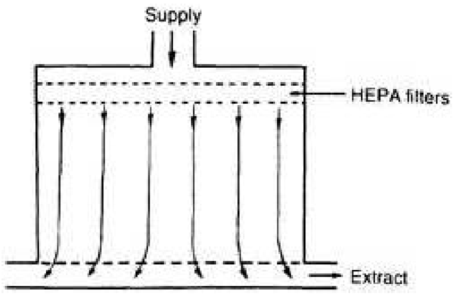


Figure 7 LEV (H.B.AWBI, 2003)

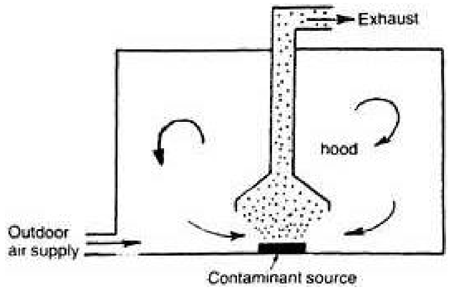


Figure 8 Piston ventilation (H.B.AWBI, 2003)

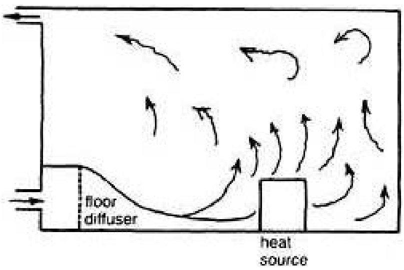


Figure 9 Displacement ventilation (H.B.AWBI, 2003)

1.6.4 DOMESTIC HOT WATER (DHW)

Domestic Hot Water (DHW) refers to the hot water that is delivered to the people for domestic purposes such as drinking, cooking, sanitation, and personal hygiene etc. In general, apartments have a high gallon hot water heater that provides hot water to the building. In order to calculate the efficiency factor of the DHW system, following equations are used:

$$EF = \frac{M * C_p * (T_{tank} - T_{inlet})}{Q_{dm}}$$

EF = Energy factor (-)

M = Mass of the water drawn (kg)

C_p = Specific heat of water (kWh/kg/˚C)

T_{tank} = Water heater thermostat setpoint temperature (°C)

T_{inlet} = Inlet water temperature (°C)

Q_{dm} = Water heater’s daily energy consumption (kWh)

The efficiency factor of the DHW system is the percentage of heat loss per hour.

1.7 INDOOR ENVIRONMENTAL QUALITY (IEQ)

While designing the building or the system’s network, it is very important to consider the occupant's comfort. The internal temperature of the building, lighting, noise, and others affect the workings of the occupants. To provide comfort and good indoor environmental quality, control systems are applied to the building that command actuators to provide action to minimize the unusual event. People spend 60-90% of their lives in the buildings (Kephalopoulos, Oliveira Fernandes et al. 2011). Occupants' thermal comfort is the satisfaction of the users that is important in both residential and non-residential buildings. It refers to the well-being of the users and how to balance the heating, ventilation, and cooling in the buildings. Achieving occupants' thermal comfort is an important aspect of creating healthier, efficient, and sustainable living and working environments. The indoor environmental quality refers to the following:

- Air quality
- Thermal comfort
- Lighting quality
- Acoustic comfort
- Moisture and mold control
- Occupant’s control.

Figure 10 shows the workings of the sensor and actuators. The CO_2 sensor measures the concentration of the CO_2 in the space. If the concentration exceeds the limits defined by WHO that is 4mg/m^3 in 2021 (WHO, 2021) then the system commands the actuators to work accordingly.

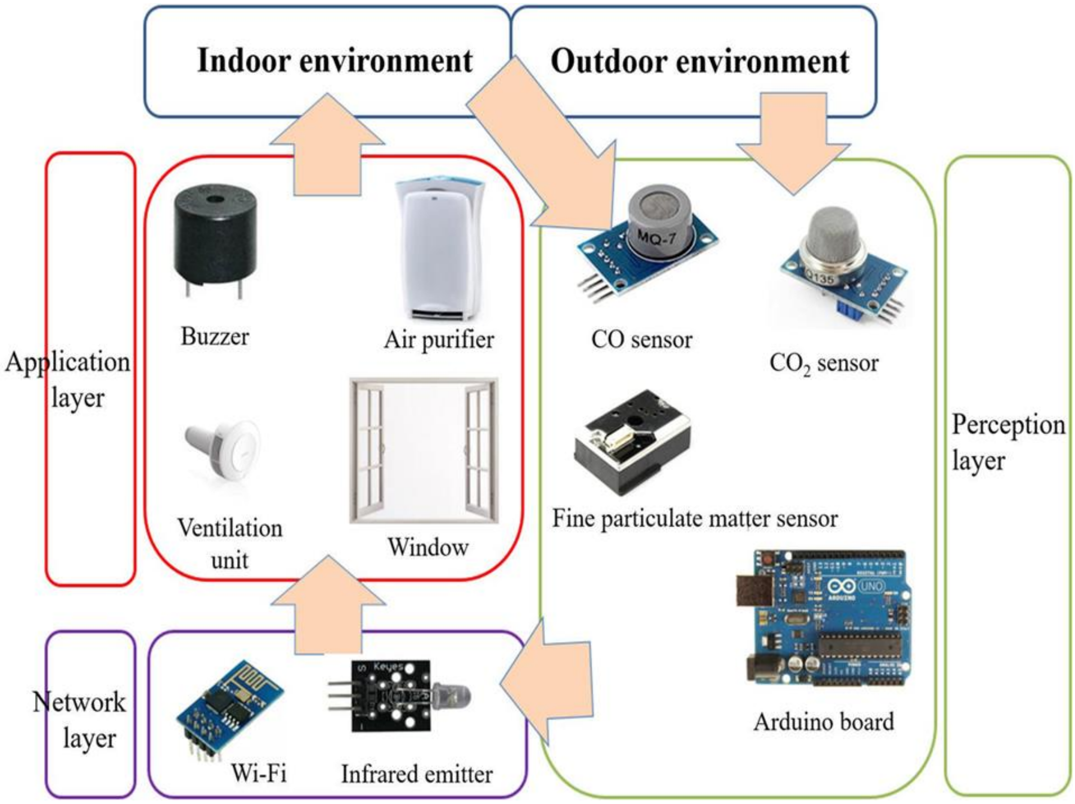


Figure 10 The system architecture based on the concepts of the IoT smart home (Sung and Hsiao 2021)

1.8 NZEB AND TRENDS TOWARD THE LOW CARBON BUILDING STOCK IN EUROPE

The net zero energy buildings are the future and solution for the decrease in the energy demand. “They are defined as buildings with very high performance and very low amounts of energy that are required to be covered to a very significant extent by renewable energies” (Maduta, Melica et al. 2022). The total CO_2 production is zero and the excessive energy can be sold to the grid. The Figure 11 shows the timeline of the net zero energy building implementation (Maduta, 2022).

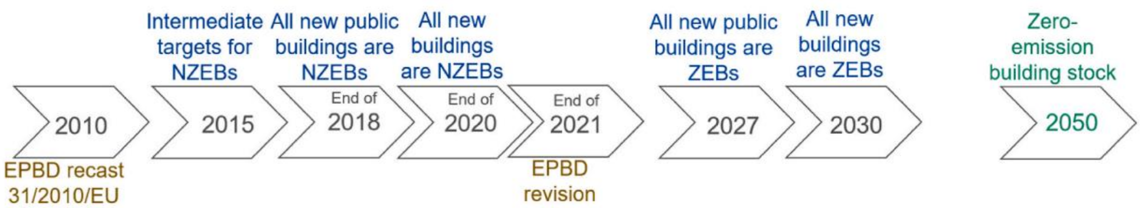


Figure 11 Timeline for ZEB and NZEB implementation (Maduta, 2022)

As shown in the Figure 12, there are multiple types of buildings and it can be seen that in the NZEB, energy from the grid is equal to or greater than zero.

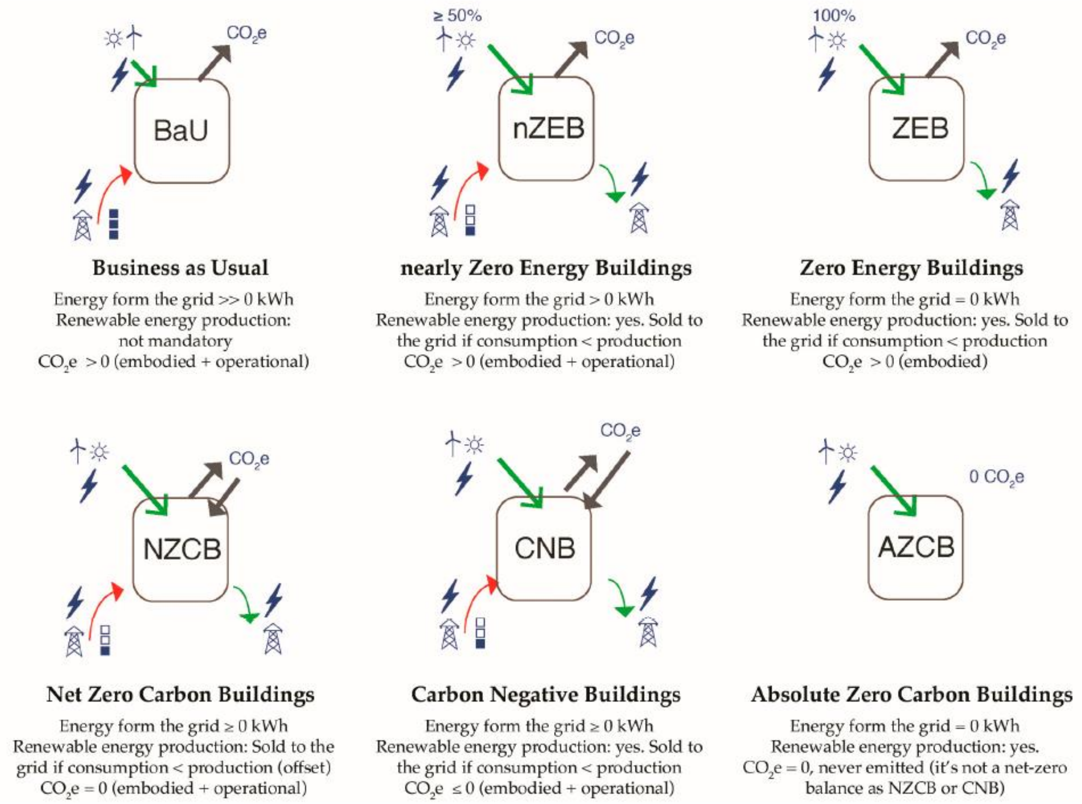


Figure 12 Different types of buildings (Tirelli and Besana 2023)

NZEBs are very important for the future as they tackle most of the problems of climate change and energy. It is a sustainable way to build buildings and most of the developed countries have passed the law for the building to be constructed according. These buildings can store energy and sell the excess energy to the national grid or nearby buildings by smart grids and smart metering (Rodrigues, Cardoso et al. 2020) The policymakers are working on the NZEBs as they are environmentally friendly and energy efficient. More of the NZEBs should be implemented in the future.

2 CHAPTER 2: LITERATURE REVIEW

In this chapter, different bibliography will be cited and explained. It is important to know the previous research and projects, how they integrate with the current research. The references of certain important parameters and legislations will be explained to aid in the explanation of this research. Following headings describe the important aspects and parameters that will be used in the research work.

2.1 ENERGY AUDIT OF BUILDINGS

An energy audit is one of the comprehensive methods to check the primary energy consumption of the buildings. “It is a process of examining an energy account and also checking ways energy is used. After the energy consumption details, in the energy audit, we identify the areas where wastage can be minimized” (Lee 1993) .There are multiple advantages of an energy audit as it helps with the money returns (cost saving, net metering, etc.), high value of property, and less emission of pollutants. An energy audit serves as a diagnostic tool to identify weak points within the building's energy consumption system, discover ways to save energy, and encourage people to be responsible about saving energy (Wang, Huang et al. 2008). “The reduction of energy consumption in public buildings is a priority indicated in European Directive 2010/31/EU” (Union 2010b). The energy audit has a set of procedures indicated in the EN 16247-2:2014 standard:

- Geometric survey of the building
- Identification of the spaces such as heated or nonheated
- Enlisting the characteristics of the technical building system
- Total energy consumption data
- HDD (Heating Degree Days) and CDD (Cooling Degree Days)
- IEQ and occupant’s behaviour

“Later, the energy refurbishment is performed in the building that must follow the recent national laws on the energy performance requirements” (Italy 2015a). The energy efficiency measures are then assessed according to their effect also considering the cost-benefit ratio of the process. Conducting an energy audit for a group of large buildings lets us study and plan smart improvements on a bigger scale, which can be useful for global analyses and strategies

(Magrini, Gobbi et al. 2016). E. Annunziata et al explained in brief about the capacity building of energy efficiency (Annunziata, Rizzi et al. 2014). Malik Sameeullah et al (Malik Sameeullah 2014) as shown in Figure 13 , studied how energy was used in hostel buildings at the National Institute of Technology in Kurukshetra. They mainly looked at how much energy was used for lighting and fans. Their research showed that by making certain changes, they could save around 463 megawatt-hours (MWh) of energy, which is roughly equivalent to a 21% reduction in energy consumption. The energy audit is performed by the auditor and it has various types that can be as follows (Sikora and Siwek 2018)

- Due to the level of detail (Preliminary, detailed)
- Due to the position of ordering person (User, bank)
- Due to scope (Fragmentary, detailed)
- Due to the contractor (Auditor, user)
- Depending on the type of building (Residential, industrial, and energy management of community)

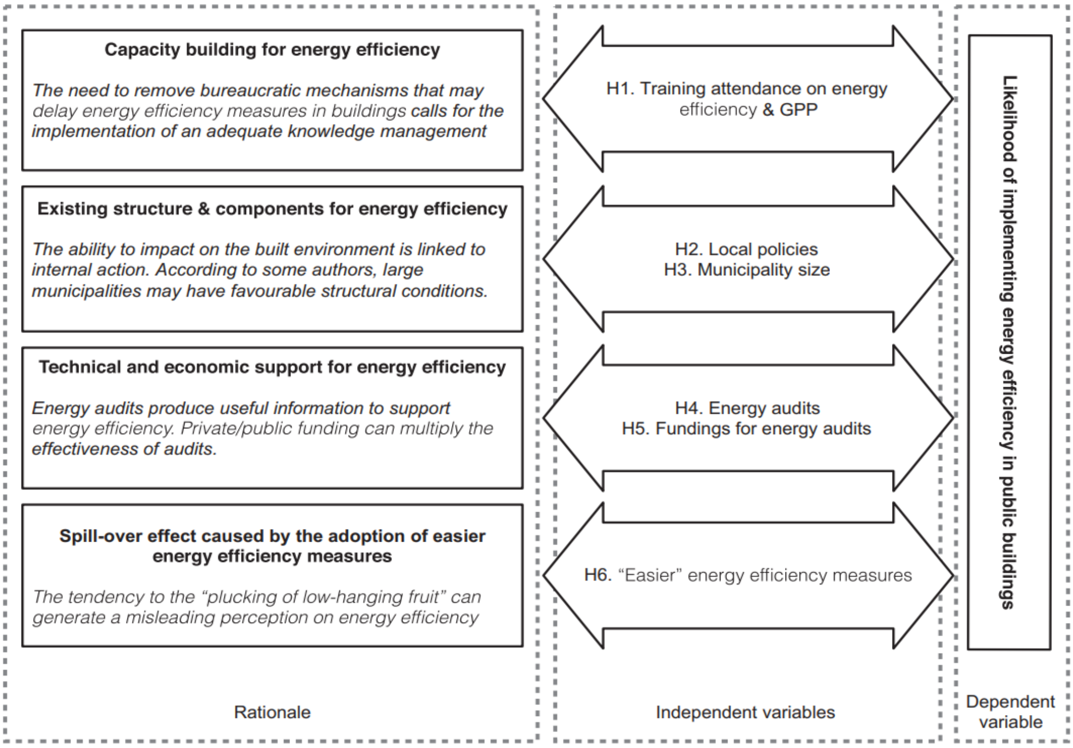


Figure 13 Graphical Representation of Conceptual Management (Malik Sameeullah 2014)

2.2 ENERGY PERFORMANCE CERTIFICATIONS

Italian law made EPCs mandatory in 2013 in which buying a property require EPC which is valid for 10 years only. It is important to see the EPC before buying or renting. The Energy Performance Certificate model was introduced through a decree on June 26, 2015 in Italy. Over time, starting from Law no. 373/1976 (Italy 1976), and progressing through L. 10/1991, and up to the latest European directives, regulations aimed at reducing energy consumption in building and plant systems have become more comprehensive and stringent, aligning with European energy efficiency objectives. An EPC (Energy Performance Certificate) is a document that evaluates the energy rating or classification of the building. EPCs are required when the stand-alone property exceeds 50 square meters while built, sold, or rented. They are made by using the standard methods and legislation about energy use. EPC has two parts as:

- **Graphic rating:** It is calculated on the energy performance of the building that also includes services such as heating, lighting (only for non-residential buildings), cooling, and DHW. It also indicates how good is the building in terms of energy performance. If the building has an A4 level that means it is a highly efficient building while if it has a G level that means it requires refurbishment or renovation. Figure 14 shows the graphic rating of buildings energy classification.

Figure 14 Energy classification of building

- **Recommendation report**

EPC is a legal document, and it must be presented if the property is sold, rented, or built. As said by Isachsen et al "parts of the certificate, for instance, the Energy Label, can be used as a short version." (Isachsen, 2020). The document has some important information, including (Sikora and Siwek 2018):"

1. Building Details: It tells you about the building and who's in charge of giving the certificate.
2. Saving Energy Tips: It gives ideas on how to use less energy in the building, which can save money and be better for the environment.
3. General Tips: Besides energy tips, it might have some other suggestions for people who want to buy or use the building to help save energy and be eco-friendly."

Jon Olaf Olaussen et al concluded three interpretations in the research. "First, energy labels of dwelling are correlated to energy performance. Second, the aesthetic appearance of a dwelling is correlated with the energy label and is responsible for the positive price effect. Third, people are not concerned with the energy performance or energy label" (Jon Olaf Olaussen 2017).

2.3 RENOVATION AND REFURBISHMENT

During the Energy Audit of the building, the energy efficiency measures are assessed. It is decided then if the building requires the refurbishment. If the overall building thermal envelope gross area fraction undergoing envelope renovation is greater than 50% then it is major renovation 1st level, if it is between 25% and 50% it is major renovation 2nd level and if it is less than 25% then it is energy refurbishment according to DM 26-06-2015 (Italy, 2015b). If the systems are not modified than renovation more than 50% of gross envelope area is also accounted for 2nd level major renovation. The renovation and refurbishment of the systems are done to increase the energy performance of the building. There are limitations due to the standards and legislation. Renovating a building presents an opportunity to not only update its aesthetics but also to enhance its overall technical capabilities "The need for refurbishment arises when we require better-quality housing and energy efficiency. Building refurbishment cuts across many different disciplines. Refurbishment includes among others structural considerations" (Lawson 2000) , waste and recycling (Gade 2022) , and the use of floor (Ravetz 2008). Considering the limited availability of fossil fuels and the reliance on them in the built environment, there is a suggestion to achieve zero carbon emissions through a structured refurbishment process as shown in Figure 15 (Xing, Hewitt et al. 2011).

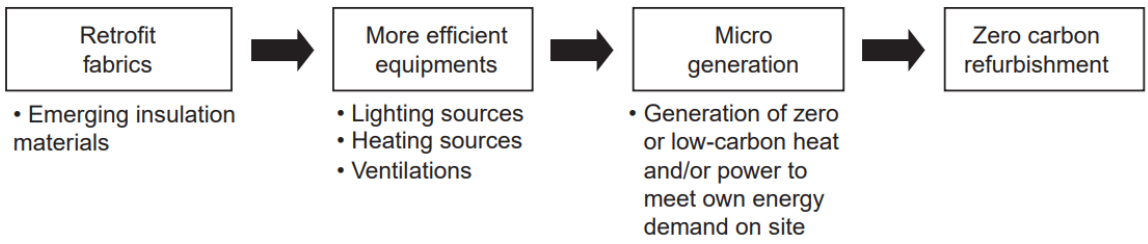


Figure 15 A hierarchical process towards zero carbon refurbishment (Xing, Hewitt et al. 2011)

Genre et al. highlighted energy performance, indoor air quality, and retrofit (EPIQR) as a decision tool combining technical, financial, energy, and comfort analysis for refurbishment (Genre, 2000) .

2.4 ENERGY EFFICIENCY MEASURES

The energy efficiency measures (EEMs) are the techniques or methods that aim at decreasing energy consumption of the building. These measures increase the effectiveness of energy utilization and reduces the wastes and energy-related expenses, and it can be applied across various sectors such as residential or non-residential. The use of EEMs helps in decreasing the greenhouse gases emissions from the buildings. There are two types of energy efficiency measures such as active EEMs and passive EEMs. These EEMs are applied to the building to improve its classification. Table 2 shows the different types of energy efficiency measures.

Table 2 Different types of EEMs (Bianco Mauthe Degerfeld, 2023)

EEM1	External wall thermal insulation
EEM2	Roof (or upper slab) thermal insulation
EEM3	Floor (or lower slab) thermal insulation
EEM4	Windows replacement
EEM5	Installation or replacement of solar shading devices
EEM6	Installation or replacement of the space cooling generator with high-efficiency technologies
EEM7	Installation or replacement of the space heating generator with high-efficiency technologies

EEM8	Installation or replacement of the DHW generator with high-efficiency technologies
EEM9	Installation or replacement of the combined generator for space heating and DHW with high-efficiency technologies
EEM10	Installation or replacement of the combined generator for heating, DHW, and cooling with high-efficiency technologies
EEM11	Installation of a thermal solar system
EEM12	Installation of a photovoltaic system
EEM13	Installation or replacement of the heat recovery for the mechanical ventilation system with high-efficiency technologies
EEM14	Installation or replacement of the control system with high-efficiency technologies
EEM15	Installation or replacement of the lighting system with high-efficiency technologies

Table 2 indicates multiple types of EEMs, orange colour (EEM 1-5) indicates the measures regarding building envelope, yellow (EEM 6-10, 13-15) indicates the measures regarding the technical building systems and green (EEM 11,12) indicates the measures for renewable energy production. From EEM 1-5 are the passive energy efficiency measures and rest are the active energy efficiency measures. The passive energy efficiency measures focus on the change of the stratigraphy of the building. Mills and Rosenfeld (Mills and Rosenfeld 1996) examined the advantages that are associated with the development of EEMs. The presented the framework for the EEMs by which high level energy performance can be achieved. They acknowledge the significance of national level benefits associated to EEMs such as enhanced competitiveness, energy security and environmental preservation. They focused on the advantages that are related to EEMs on national and human level.

2.5 OVERVIEW OF THE EXISTING BUILDING STOCK AND ITS ENERGY CONSUMPTION

Existing building stocks means all the structures that have been built or are in use. There are different categories of the buildings according to their use, design, age and EEMs levels. The energy consumption in the building indicates its efficiency levels (CRESME, 2009). In

Lombardy region about 90% of the existing buildings, totalling 1,339,468 units, were constructed before the enactment of Italy's significant energy-saving legislation, L. 10/1991. The structures in this region had low energy efficiency measures and high energy consumptions. “The building sector is an important contributor in the overall energy consumption landscape of the Lombardy region as it contributes for the 41% of the energy consumptions. In this percentage the total residential buildings have 29% and the non-residential have 12% share.” (CEER). In another scenario, Selvino town that is located near Bergamo has buildings share of 80% of the local energy consumption. In this share, 68% belongs to the residential sector. As most of the energy production is from the fossil fuels so the buildings sector has high share in the production of CO_2. The buildings should have low energy consumption or self-production through renewables so that less greenhouse gasses are produced.

2.6 OBSTACLE TOWARDS THE ENERGY SECTOR

There are some major barriers to energy efficiency in the building sector as follows (SBCI 2009):

- **Economic/ financial barriers:** Energy subsidies provided to the people
- **Hidden costs/benefits:** Expenses and potential risks arising from compatibility issues, performance uncertainties, transaction expenses, and similar factors.
- **Market failures:** Failure of the market such as stocks or others
- **Behavioural and organizational barriers:** There are problems in the developing countries that are the electricity thefts. There are high load shutting and workers also go for strikes.
- **Information barriers:** Insufficient awareness among consumers, building managers, construction firms, and political figures.
- **Political and structural barriers:** Leaders have lack of knowledges.

2.7 TECHNICAL STANDARDS

Figure 16 indicates the list of some standards that are used in the research work. It is important to know the details before applying them to the research work.

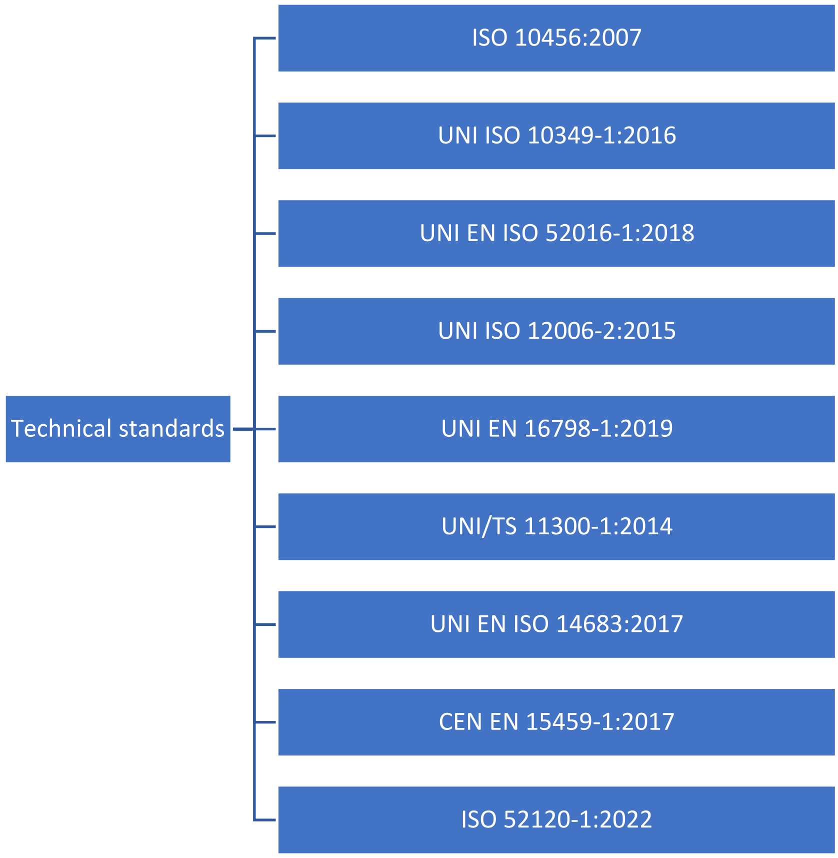


Figure 16 Technical standards used in research work

In the following headings, some of the normative will be explained in detail and their connection with others.

2.7.1 BUILDING CATEGORY (DPR 412/93 and UNI ISO 12006-2:2015) (Standardization 2015)

The buildings are classified by its use and it is represented by the codes that aligns with the rules and regulations. By Italian legislation, particularly the Decreto del Presidente della Repubblica N° 412 of 1993, Article 3 provides a detailed classification of buildings into different categories based on their use. According to this Decree, buildings are divided into the following classifications as shown in Table 3.

Table 3 Classification of buildings

<table>
<tr><td>Building Category</td><td>Use</td><td>Building Subcategory</td><td>Description</td></tr>
<tr><td rowspan="3">E.1.</td><td rowspan="3">Buildings used as residences or similar</td><td>E.1.1.</td><td>Residences with character continuous, such as civil and rural homes, colleges, convents, prison houses, and barracks;</td></tr>
<tr><td>E.1.2.</td><td>Spaces used as residences with occasional occupation, such as holiday homes, weekends, and the like;</td></tr>
<tr><td>E.1.3.</td><td>Buildings used as hotels, guesthouses, and activities similar</td></tr>
<tr><td>E.2.</td><td colspan="3">Office buildings and similar: public or private, independent or contiguous to buildings also used for activities industrial or artisanal, provided they are of such buildings separable from the effects of thermal insulation;</td></tr>
<tr><td>E.3.</td><td colspan="3">Buildings used as hospitals, clinics or nursing homes and similar, including those used for hospitalization or care of minors or elderly, recovery of drug addicts, and other subjects entrusted to public social services;</td></tr>
<tr><td rowspan="3">E.4.</td><td rowspan="3">Buildings used for recreational activities, associations, or cults and similar;</td><td>E.4.1.</td><td>Cinemas and theatres, meeting rooms for congresses;</td></tr>
<tr><td>E.4.2.</td><td>Exhibitions, museums and libraries, places of culture;</td></tr>
<tr><td>E.4.3.</td><td>Bars, restaurants, dance halls;</td></tr>
<tr><td>E.5.</td><td colspan="3">Buildings used for commercial and similar activities such as shops, wholesalers or retail stores, supermarkets, exhibitions;</td></tr>
<tr><td rowspan="2">E.6.</td><td rowspan="2">Sports Building</td><td>E.6.1.</td><td>Swimming pools, saunas, and similar;</td></tr>
<tr><td>E.6.2.</td><td>Gyms and similar;</td></tr>
</table>

		E.6.3.	Support services for sporting activities;
E.7.	Buildings used for school activities at all levels and similar;		
E.8.	Buildings used for industrial and artisan activities and similar.		

2.7.2 UNI EN ISO 52016-1:2018 (UNI 2018c)

This normative document outlines the prescribed methodologies for evaluating the following:

- Calculation of the sensible energy requirement for both heating and cooling on hourly monthly basis
- Assessment of latent energy demand for dehumidification on a monthly or hourly basis.
- Monitoring and analysis of internal temperature on an hourly basis.
- Determination of the hourly sensible heating and cooling loads.
- Calculation of moisture and latent loads required for dehumidification on an hourly basis.
- Calculation of the design sensible heating or cooling load and latent heat load on hourly basis
- Specification of the conditions for supply air, ensuring it meets the humidification and dehumidification requirements.

UNI EN ISO 52016-1 is applicable for both residential buildings and non-residential buildings that are either existing or at the design stage.

2.7.3 CLIMATIC CHARACTERIZATION (UNI 10349-1:2016) (UNI, 2016)

In this standard, the monthly average values of temperatures, vapor pressure, daily solar irradiance in the horizontal plane, and wind speed are reported. ENEA in Italy collects the climatic data from met towers. It is important to have the hourly, monthly, or annual data for the A3 evaluation that is energy audit. The ASHRAE Level-3 audit involves a much more detailed information collection over a period of weeks or even months while level 1 includes the walk-through survey and level 2 includes the energy survey and analysis of building (ASHRAE, 2014). It is the detailed analysis of capital-intensive modifications. These climatic indicators/parameters have a high impact on the building's energy consumption. For example, during the daytime, the solar irradiance is higher and the temperature difference between indoors and outdoors is less, so the energy required to heat the building is less. Also, wind is a big factor for the ventilation of the building. Factors like relative humidity, vapor pressure and pressure have high impact on buildings consumption.

2.7.4 BUILDING MATERIALS AND PRODUCTS (ISO 10456:2007) (Standardization, 2007)

The above-mentioned standard shows the techniques for establishment of design thermal characteristics for building materials and shows their thermal properties. It also describes some methodologies and procedures that are applicable from the -30 degrees ˚C to 30 ˚C. It also provides the conversion factors for temperature and moisture. The standard has values in tabular forms that are used in the calculation of the heat transfer through the component. These calculations are linked to different types of materials that are used for the construction of the building.

2.7.5 THERMAL BRIDGE (UNI EN ISO 14683:2017) (UNI, 2018d)

This above mentioned normative specifies the application of simplified methods to assess heat transfer phenomena occurring at linear thermal bridges that are in the joints of the components. It also provides detailed information about the manual calculation procedures for these thermal bridges. The outputs of this normative are the calculation of the linear and point thermal bridge and transmittance. The linear thermal bridge is the cross-sectional configuration along one of the three orthogonal axes and the linear transmittance is steady-state heat transfer rate divided by the length of the thermal bridge and the temperature difference between the two sides of the bridge. While the point thermal bridges are single penetrations in the thermal envelope of the building and point thermal transmittance is the steady-state heat transfer rate, divided by the temperature difference between the two sides of the point bridge. The heat transfer flow rate is calculated by:

$$\phi = H_T(\theta_I - \theta_e)$$

..............................Eq 4

Where,

Φ = Heat transfer flow rate (W)

H_T= Heat transfer coefficient (W/K)

θ_i= Internal temperature (˚C)

θ_e= External temperature (˚C)

The transmission heat coefficient depends upon the building envelope, ground heat transmission, and heat transmission. The following relation is used when dealing with liner transmittance.

$$H_D = \sum_i A\,Ui + \sum_k l_k \Psi_k + \sum_j X_j$$

..............................Eq 5

Where,

A_i= Area of the element (m^2)

U_i= Thermal transmittance of element (W/m^2K)

L_k = Length of thermal bridge (m)

Ψ_k= Linear thermal transmittance (W/mK)

X_j = Point thermal transmittance= Negligible

2.7.6 ENERGY PERFORMANCE OF BUILDINGS (UNI/TS 11300-1:2014) (UNI 2014a)

The above normative provides the detailed information and calculation for different services such as DHW, heating and cooling. It provides a calculation method for determining the primary energy requirements for ventilation services and offers guidelines and national data for calculating the primary energy requirements for lighting services. It provides the methodologies to find the efficiency and the losses in the generation subsystems.

2.7.7 UNI EN 16798-1:2019 (UNI 2019)

This standard specifies requirements regarding indoor environmental parameters, adding aspects related to thermal conditions, indoor air quality, lighting, and acoustics. Furthermore, it guides how to determine and establish these parameters for the design of building systems and calculations related to energy performance. This European Standard provides the calculation method for determining the primary energy requirement for the ventilation service and the indications and national data for determining the primary energy requirement for the lighting service. It is useful for the situations in which the indoor environment conditions is dependent of the occupants. It also provides the occupancy schedules for multiple parameters, and it applies to all types of buildings such as newly designed, or existing.

2.7.8 CONTRIBUTION OF BUILDING AUTOMATION, CONTROL, AND BUILDING MANAGEMENT (EN ISO 52120-1:2022) (UNI 2022i)

This norm specifies the following:

- List of the BACS (Building automation and controls systems) that can be added to the building to contribute to energy efficiency.
- A method to define the minimum requirement or specification of the BACS
- Method to get the effect of the BACS on typical buildings.

BACS are the assets added to the building that increase the efficiency of the system and improve the building's energy. The main functions of BACS are to maintain control of the building environment, command the systems according to the indoor environment to set according to comfort, monitor the performance of the systems, and alert if there is any problem. It should be included in all types of buildings residential or non-residential.

2.7.9 ECONOMIC EVALUATION PROCEDURE (CEN EN 15459-1:2017) (CEN, 2017)

This standard illustrates different systems of the building that influence the energy demand and consumption of buildings. It is applicable to all types of buildings, whether they are newly constructed or existing structures. Its core components include:

1. Definitions and the categorization of cost types that must be considered when evaluating the economic efficiency of energy-saving measures in buildings.
2. Data necessary for the calculation
3. Calculation process
4. Economic analysis of the EEMs

This European Standard is an integral part of the methodology used to assess the economic performance of energy-saving measures in buildings. The measures are listed above in the EEM sections. The specific focus of this part of the standard is to standardize:

1. Inputs for economic evaluation
2. Outputs of the evaluation
3. Mathematical formulas are employed in the calculations.
4. Impact of systems

3 CHAPTER 3: METHODOLOGY

This section will delve into the methodology employed in our research endeavour. Here, we aim to provide a comprehensive overview of the project's progression. It is important to note that this research is part of the TIMEPAC project. The research work describes how the EPC schemas use operational data integration. The energy audit is done on multiple buildings in partner countries and data collected helps in improving the process of energy performance certification. As discussed above in the literature review, there are multiple obstacles in the way of energy performance certifications and the solution is to ease the process of the EPCs. This can be only done by gathering multiple data around the work and finding where the problems lie and how they can be solved. The focus of the research work is to perform an energy audit on the building and provide the deliverables to the TIMEPAC.

3.1 TIMEPAC FRAMEWORK

The objective of TIMEPAC WP1 (Work Package 1) is to study the elements that are involved in the development of energy performance certificates using the stages of EPC as generation, storage, analysis, and exploitation as shown in Figure 17. Based on the studies by WP1 the problems, threats, and risks are identified. There would be continuous data that involves multiple stakeholders to make effective EPCs.

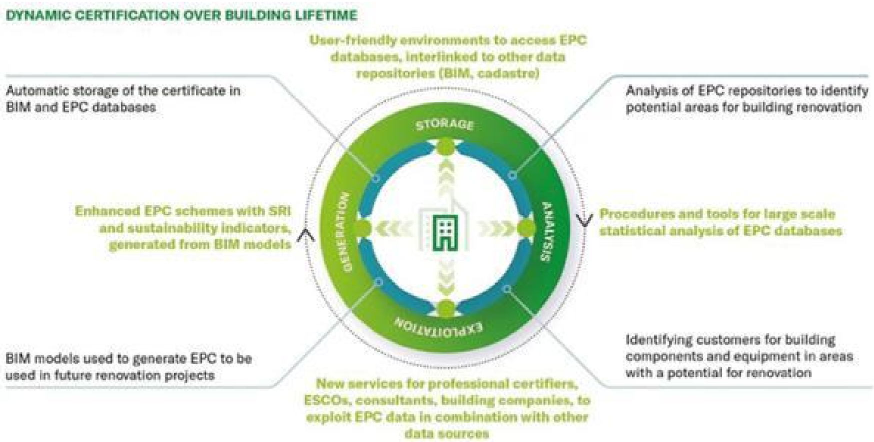


Figure 17 A holistic approach to energy-performance assessment and the certification of buildings -continuous EPC data workflow connecting various stages and stakeholders. (TIMPEPAC 2022b)

3.1.1 GENERATION

In this section, the results are generated using the simulated building model in certain software's. The generation of the data has certain set of procedures described by TIMEPAC. These data are later stored and analysed. To improve the performance of the building it is necessary to follow an integrated approach considering the envelope and technical systems of the building. The energy performance of the building should be evaluated based on calculated or actual metered energy use. It must include the ventilation, heating, cooling, lightning (for non-residential buildings) and other technical systems data. The challenge of the current research is enhancing the energy performance certifications by improving the quality of the information. There should be an inclusion of the actual energy consumption data and targeted energy efficiency measures. In the process of the continuous workflow of EPCs, the main challenge is to add all the positive elements without making the process complex and costly for the users. The success of improved EPC lies on skilled technicians, having further education in evaluating a structure's energy efficiency and formulating effective strategies to decrease energy usage.

3.1.2 STORAGE

The data after the generation phase is stored in TIMEPAC database. "EPC databases in all six TIMEPAC countries (Austria, Croatia, Cyprus, Italy, Slovenia, and Spain) are linked to, or are getting data from, the corresponding cadastre databases, there are still connections missing with other databases, such as BIM repositories, statistical databases and databases for the technical inspection of buildings." (TIMPEPAC, 2022b). The data stored will be a part of enhanced EPC schemes. In the process of generating an EPC, particularly when evaluating the energy performance of intricate buildings, a substantial volume of data undergoes processing as illustrated in Figure 18. It could be seen that the data collection process are quite complex, as the in site inspection data includes the buildings dimensions, technical building systems, building use and building management. These data are also taken by other means such as provided data, user interview or documentation etc. There is a vast set of data that is stored in the EPCs database. Later this data is analysed and evaluated to enhance the EPCs schemas.

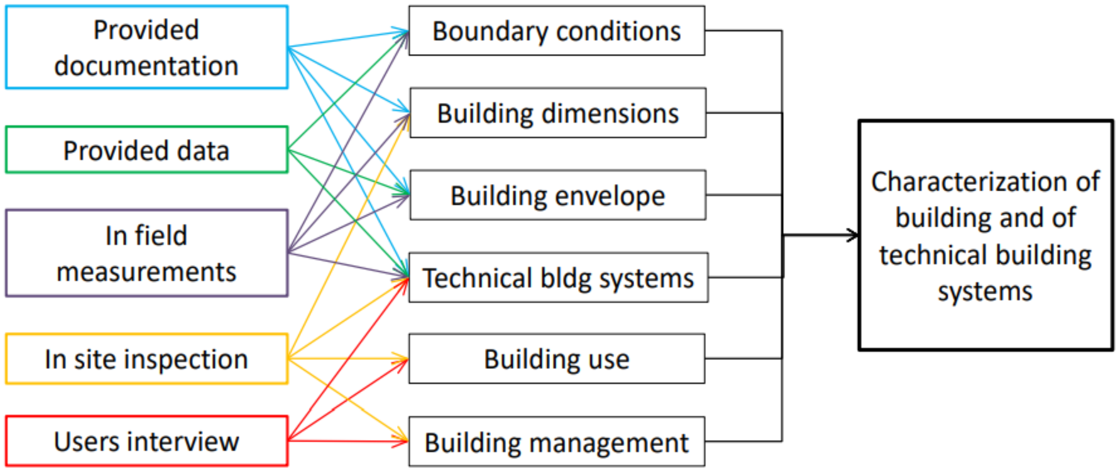


Figure 18 Complexity of the data-collection process during the EPC generation (TIMPEPAC 2022b)

3.1.3 ANALYSIS

After the storage of the data, the data quality will be analysed depending on three factors:

- Validity of input data ,
- EPC calculation methodology and applied tools,
- Assessor's qualification

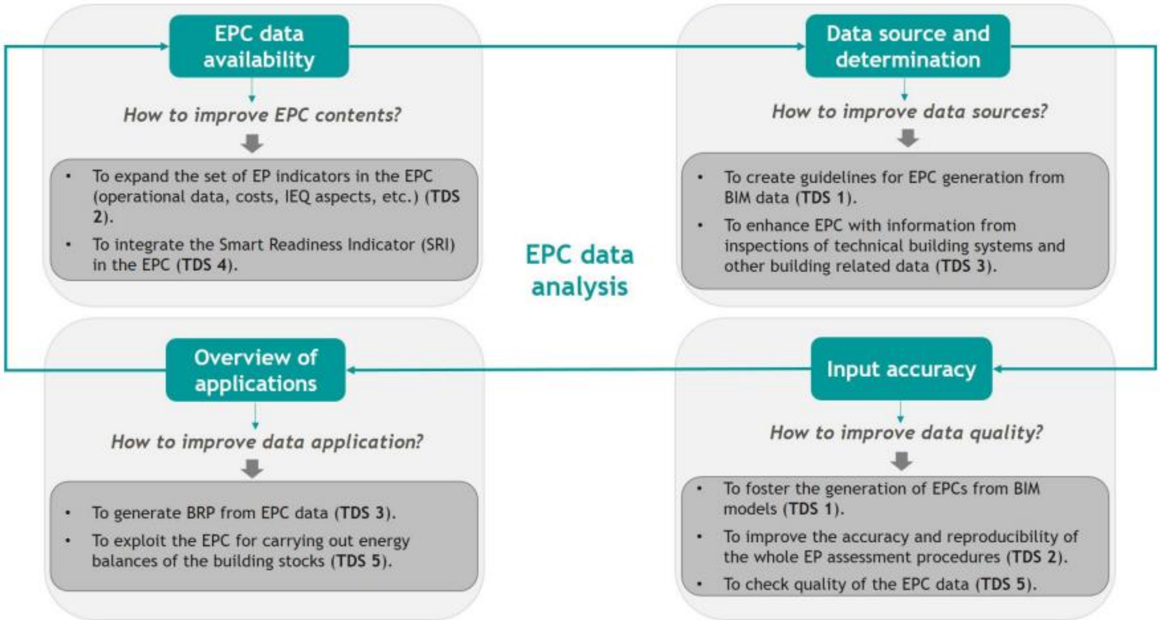


Figure 19 Relationship between the outcomes of the analysis conducted in Task 1.3 and the objective of TDS (TIMPEPAC 2022b)

Above Figure 19 explains the EPC data analysis. There is also a description of the multiple TDS in TIMEPAC. With the EPC data availability, we analyse that how to improve the EPC contents? Which means that we expand the set of Energy Performance indicators. We determine improvement of the data sources by creating the guidelines for EPC generation from the BIM data etc. In this section we also analyse that how we can improve the input data quality by improving the accuracy. Later we analyse how to improve the data application that is done by exploiting the EPC for carrying out energy balances of the building stocks.

3.1.4 EXPLOITATION

Within TIMEPAC, enhancing the quality of EPCs will involve increasing data reliability through the application of quality assurance techniques to identify errors during the EPC generation process. Furthermore, improvements to the TABULA/EPISCOPE bottom-up approach will be implemented to account for the evolving nature of buildings over time, rendering EPCs more adaptable. Additionally, to increase EPC reliability, the factors linking the computed energy usage to actual consumption will be also developed, drawing from data gathered from representative buildings. TIMEPAC will also find a methodology for the technical implementation of innovative data handling features related to the quality assurance proposed in the X-tendo project as shown in Figure 20 (Aná Maia and Lukas Kranzl , 2021).

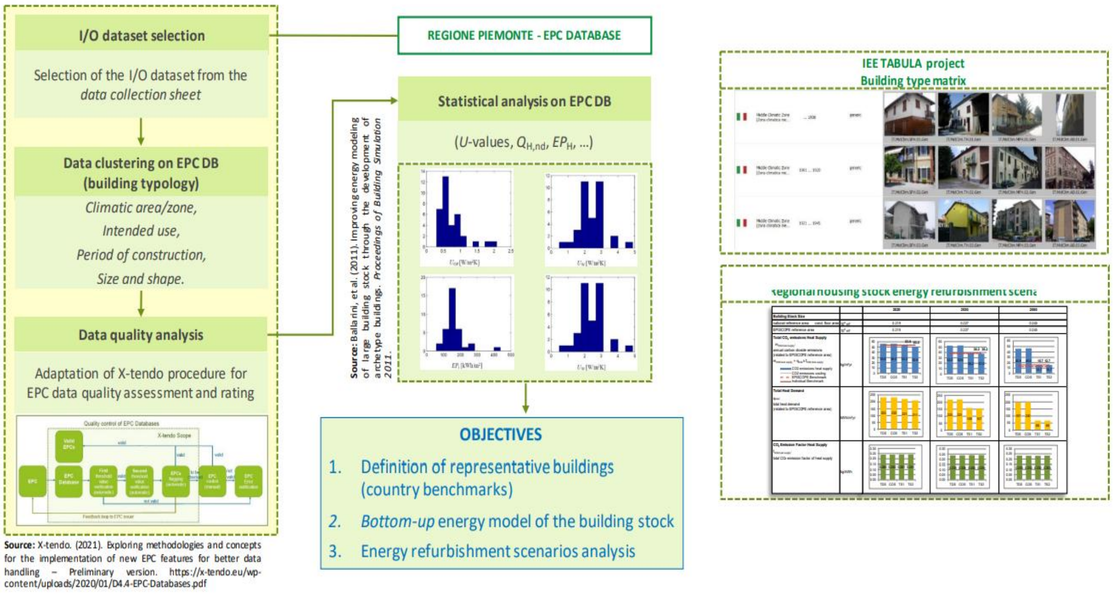


Figure 20 Outline of the TIMEPAC methodology to improve EPC data exploitation (TIMPEPAC 2022b)

3.2 WORKFLOW OF RESEARCH

The following flow diagram (Figure 21) shows the methodology of how the research proceeded.

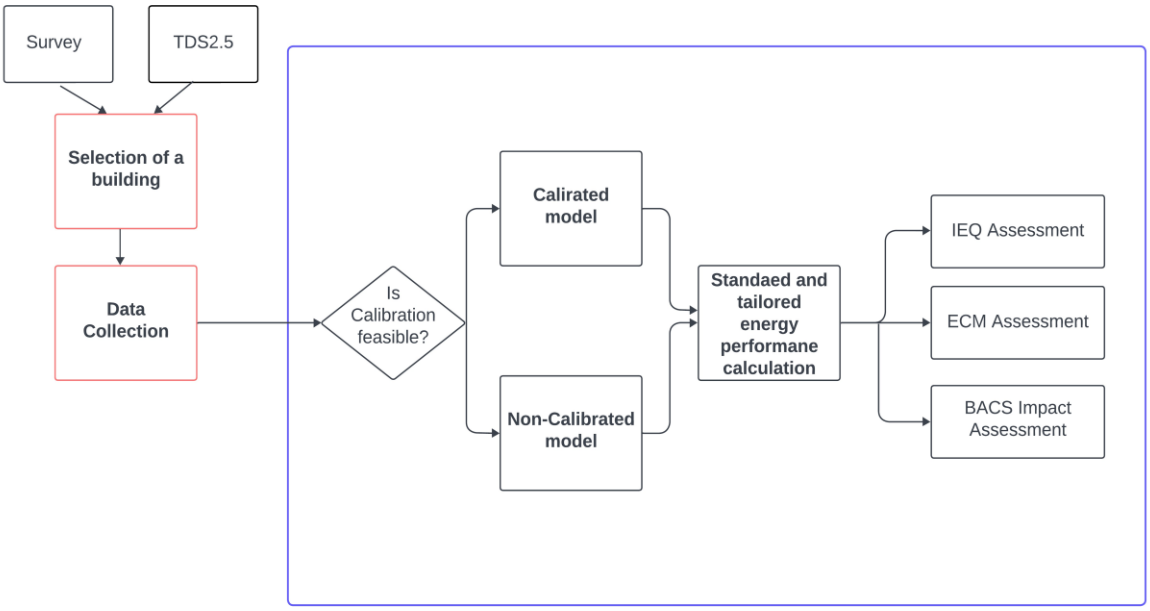
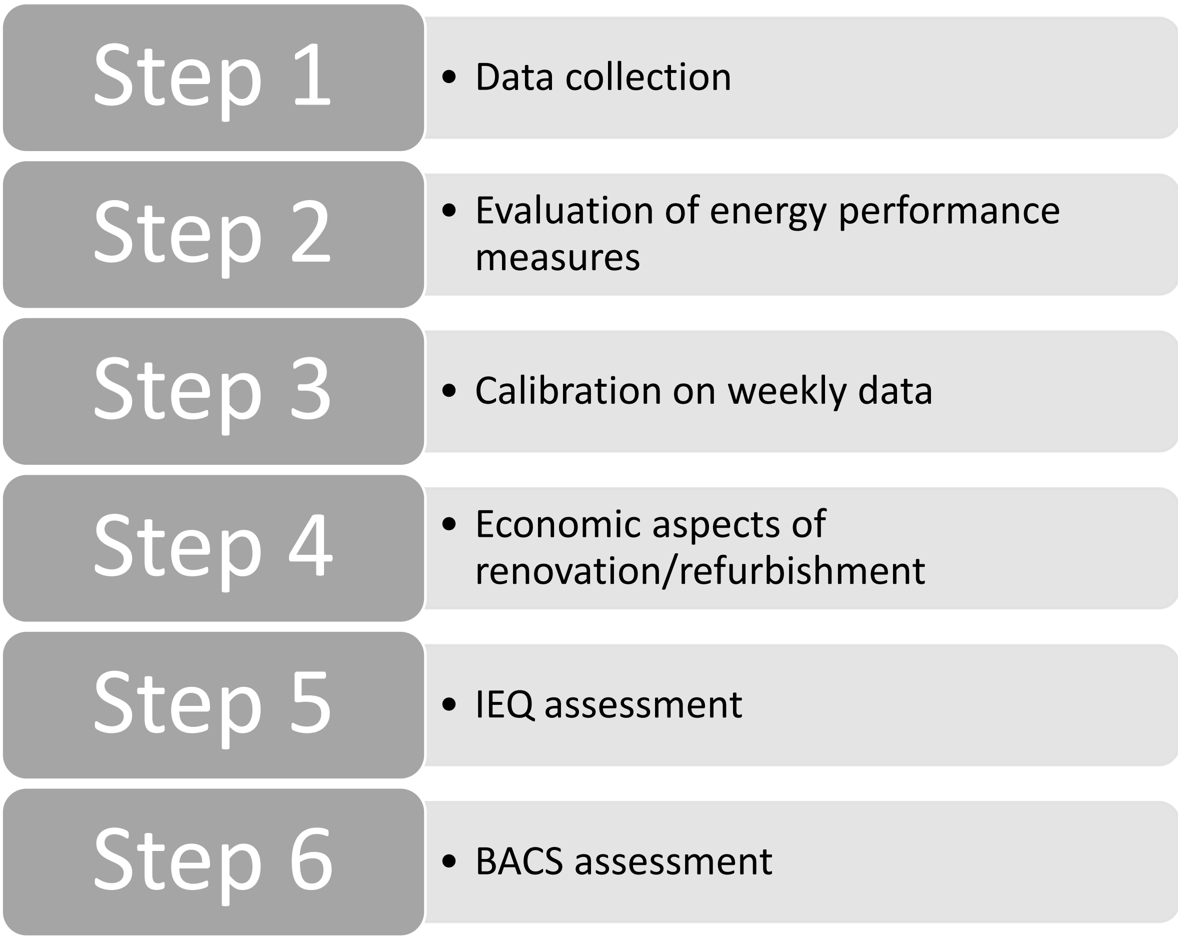


Figure 21 Methodology of research work

The partners involved in the TIMEPAC carried out the survey in which they listed different no of buildings with their construction years. Later in TDS 2.5, the acceptable ranges of the thermal transmittance for opaque and transparent components were defined for the construction years. The partners check if the component of the building lies in the acceptable range provided and has enough information then they choose the building. Later there is a site inspection in which all the data related to the building such as systems data, stratigraphy, and occupancy details. The model will be developed on the EDILCLIMA EC700 software and then simulations will be run based on the data collected. If the calibration is feasible according to the TEPA Calibration the calibrated model will be used for multiple assessments such as IEQ, ECM, and BACS. If the model is not calibrated, then certain strategies will be applied to it to make it calibrated according to the measured data. Later this data will be stored and analysed in the database TIMEPAC. The research work is divided into steps from 1 to 6 as follows:



3.2.1 STEP 1: DATA COLLECTION

The data collection can be performed by various method such as the use of the previous documentations, on site survey, national data and guidelines. It is one of the most important steps in the EPCs as the data collection should be of high quality and accurate. While using the data from the sources its reliability whether they can be used for the research activity or not. To acquire the comprehensive information about the building's energy performance, data collection requires the holistic approach. The data could be:

- Buildings Information and layout
- Systems details
- Occupancy behaviors
- Climatic data
- Potential of the renewable energies

- Billings data
- Buildings location

These data are later used for the calculation of the primary energy consumption.

3.2.2 STEP 2: EVALUATION OF PRIMARY ENERGY CONSUMPTION

Following the completion of step 1, the building undergoes an A3 energy audit. This audit generates results for various systems, including ventilation, heating, and DHW. Edilclima furnishes hourly values of $\Phi_{H/C}$ in watts over the specified timeframe. To convert these values from watts to kilowatt-hours (kW), I used the following formula:

$$\phi_{H/C}[kWh] = \frac{\left(\frac{QH,gen,out}{QH,gen,in}\right)}{1000} * 1$$

..............................*Eq 6*

After the use of this equation, the hourly values are added on to weekly basis and we get the total consumption in kWh for the simulated data for each month.

3.2.2.1 TAILORED AND STANDARD ENERGY PERFORMANCE ASSESSMENT

In standard EP assessment the steady state approach is used and climatic and building data is according to the standards. The tailored energy performance assessment represents the evaluation of energy efficiency and performance of the system in building. It uses the actual data for use, climatic data, and building. SEPA involves the evaluation and analysing of various factors that contribute to the building’s energy and efficiency. SEPA follows tge established guidelines provided by the standards and it provides evaluation on the basis of widely accepted criteria. SEPA uses the predefined methodologies that are listed by the organizations. TEPA is highly valuable as it identifies strategies and solutions to optimize the energy performance of the building. TEPA is more detailed and uses the real data to evaluate. TEPA considers the unique factors of building, and it provides the personalised evaluation.

3.2.3 STEP 3: CALIBRATION ON WEEKLY DATA

The data provided by the building is first translated into consumption values in kilojoules (kJ) for each hour. Each of these values is subsequently divided by 3,600 to convert them into kilowatt-hours (kWh). These kWh values are then aggregated every week. To assess the accuracy of the model, a calibration process is initiated. This process involves comparing measured data with simulated data on a weekly basis. Calibration is the fine-tuning of simulation inputs to align the observed energy consumption closely with the predictions made by the simulation program. The primary aim of this step is to compare the output of the simulated model with the measured data and then refine the model until an acceptable calibration is achieved. Different levels of calibration as shown in Table 4:

Table 4 Levels of calibration (Reddy, 2006)

LEVEL 1	Based on incomplete and split information due to the availability of nothing but as built
LEVEL 2	Site visits or inspections allow verifying as-built data and collect more information
LEVEL 3	Based on a detailed audit of the case study; spot measurement
LEVEL 4	Based on short-term monitoring
LEVEL 5	Based on long-term monitoring

For this building, level 2 calibration will be done on statistical and graphical data. The following flow diagram (Figure 22) shows the process of the calibration.

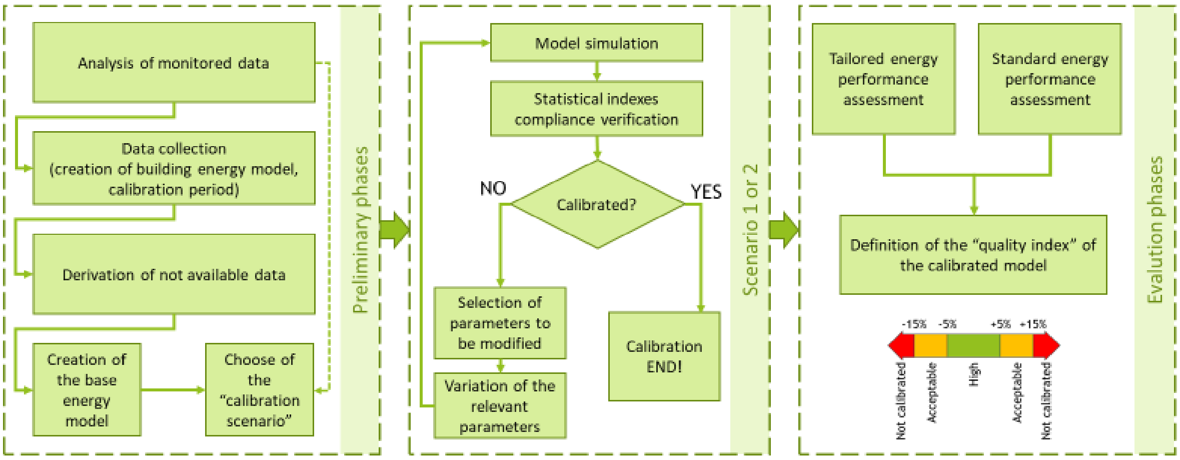


Figure 22 Flow diagram of calibration

Figure 22 shows that after the compliance of the statistical indexes if the model is calibrated then it is evaluated with tailored or standard energy performance assessment.

3.2.3.1 MEAN BIASED ERROR AND CV(RMSE)

MBE, which stands for Mean Bias Error, is a percentage-based measurement used to evaluate how closely the energy consumption predicted by a model aligns with the actual metered data over a monthly or annual timeframe. The period mentioned in the equation below is the corresponding time period of the simulated and measured energy consumption data. Period could be daily, weekly monthly or yearly data in which the outcome lies in. It can be calculated by the following equation:

$$MBE\ \% = \frac{\sum_{period}(S - M)}{\sum_{period} M} \times 100$$

..............................Eq 7

S= Simulated data

M=Measured data

CV(RMSE), or Coefficient of Variation of Root Mean Square Error, is a percentage-based error metric that serves as a normalized measure of the variability between measured and simulated data. It considers both the magnitude of the error and the dispersion of data points within the sample. It can be calculated by the following:

$$CVRMSE\% = \frac{RMSE_{period}}{A_{period}} \times 100$$

..............................Eq 8

The RMSE expressed as Root mean square error is a measure of invariability or how much spread exists in data. "A_{period}" is the average of measured energy used in each period . An average of measured energy use in each period. The statistical limits of hourly data for MBE is ±10% and for CV(RMSE) is 30% and the statistical limits of monthly data for MBE is ±5% and for CV(RMSE) is 15% by ASHRAE guideline 14-2014 (ASHRAE 2014).

3.2.3.2 GRAPHICAL METHOD

There is a graphical method by which the calibration can be analysed in which there is a daily average outdoor temperature in degrees Celsius on the X-axis while the daily energy consumption in kWh in the Y-axis. For the case of weekly data, the no of days in each interval of date is calculated for measured and simulated data. Later daily energy consumption is calculated by dividing the energy consumption of interval with the no of days. This daily energy consumption of the simulated and measured data is plotted with the daily average outdoor temperature. We analyse the trend line of each by noting the shift and difference between them. If there is a difference between trendlines slopes then we need to alter the thermal properties of building components, thermal bridges linear thermal transmittance and ventilation/ infiltration rates. If there is a shift between the trendlines then we need to modify the internal heat gain load or profiles, heating/cooling setpoints and HVACs technical specifications and profiles.

3.2.4 STEP 4: ECONOMIC ASPECTS OF RENOVATION/REFURBISHMENT

In this step, renovation or refurbishment will be done to the building to improve the energy classification of the building. Multiple energy efficiency measures passive or active have been discussed above. These measures can be applied to buildings with an economic assessment by using the NPV (Net Present Value) and DPP (Discounted Payback period). NPV and DPP can be calculated by the following:

$$NPV = \sum_{n=1}^{n} \frac{CFn}{(1 + Rate)^n} - Io$$

..............................*Eq 9*

Where,

Rate= Discount rate

CF= Cash flow in period n (€)

n= Number of periods

Io= Initial investment (€)

When NPV=0, then the year is the DPP of investment.

The cost of each element is calculated along with the labour cost, maintenance cost, and disposal cost and then NPV is calculated. There are different scenarios with different EEMs and the best scenario with the lowest DPP is chosen for the building. The scenario should comply with the NZEB law of Italian legislation. The following flow diagram Figure 23 shows the process of the ECM assessment in an energy audit.

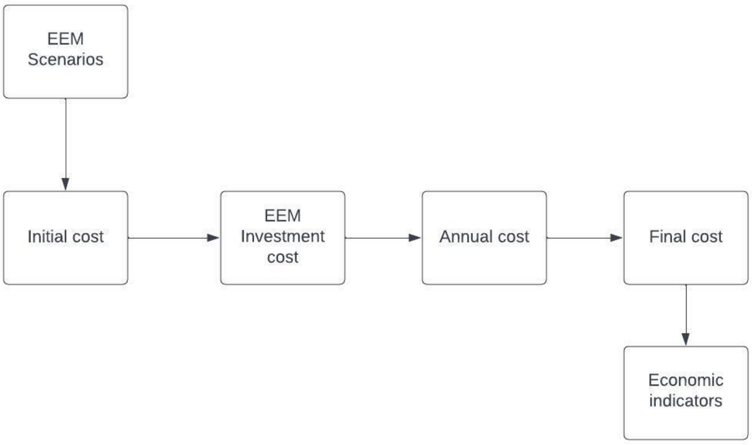


Figure 23 EEM flow diagram

3.2.5 STEP 5: IEQ ASSESSMENT

During the IEQ (Indoor environmental quality) assessment, the thermal comfort of the occupants is evaluated. In the preliminary phases of the IEQ assessment, there is an identification of the IEQ quality category, definition of thermal comfort evaluation periods, and identification of representative spaces of the building. After this phase, there is a calculation of the running mean outdoor temperature and thermal comfort temperature range. Then there is a calculation of the indoor operative temperature of the selected spaces and the percentage of hours within the comfort range. In the end, there is a definition of thermal comfort "quality index". The indoor air quality is also calculated by using the details such conditioned floor area, comfort category, polluting level and flow rate. It defines the minimum IAQ require for the building. In IEQ assessment the domains that are considered are:

1. Thermal comfort
2. Indoor air quality

3.2.5.1 THERMAL COMFORT

The thermal comfort category is important as it defines what are the expectations of the occupants regarding the indoor environment of the building. If there are children, then they require higher level while normally it is required category II that is medium. The thermal comfort evaluation is carried out according to the adaptive comfort theory and it can be applied only for periods without heating or cooling. The calculation of thermal comfort is divided into following steps:

1. **Selection of evaluation period**: The evaluation period is selected according to the requirements.
2. **Calculation of running mean outdoor temperatures:** It is taken from the climatic file used for the simulation.
3. **Definition of the operative temperature comfort range:** The operative comfort is a temperature range in which the occupant has thermal comfort inside the space. There is a total of 4 categories of the comfort defined by the EN ISO 16978-1 and is chosen by the user. The upper and lower limit of temperature are calculated and then the data is analyzed if lies in between the comfort limits or not.
4. **Calculation of thermal comfort index:** The comfort index is calculated for the occupied hours and has two indexes as percentage of comfort hours (PCH) and discomfort hours (PDH). PCH shows how many hours in percentage are comfortable under the range and the PDH shows that how many hours are in discomfort range.
5. **Definition of thermal comfort quality index:** The proposed KPI is a qualitative index that identifies the level of thermal comfort expected in the analyzed representative spaces. "This is defined by means of the percentage of discomfort hours defined by CEN/TR 16798-2:2020 as follows (UNI, 2020) :

- If $PDH \leq 3\%$, then a **high** thermal comfort level is expected,
- If $3\% < PDH \leq 6\%$, then an **acceptable** thermal comfort level is expected, and
- If $PDH > 6\%$, then a **not acceptable** thermal comfort level is expected."

3.2.5.2 INDOOR AIR QUALITY

Indoor air quality (IAQ) refers to the condition of the air inside buildings, including homes, offices, schools, and other enclosed spaces. It is a critical aspect of environmental health because we spend a significant portion of our lives indoors following the specifications of the UNI EN ISO 16798-1:2019. While calculating the indoor air quality we require inputs as comfort category, use of building, polluting level, conditioned floor area, conditioned net volume, no of occupants and designed external flow rate.

3.2.6 STEPS 6: BACS ASSESSMENT

In BACS (Building Automation and Control Systems) Assessment, multiple control strategies are applied to the building to check their effect. There are multiple controls such as heating, DHW, cooling, ventilation, lighting, and blinds control. There are multiple functions related to each control. In BACS, each function's effect on primary energy needs is evaluated with no function implemented and then the percentage reduction of Ep is calculated. In this way, we can find out the effect of each function on the building's primary energy. It plays a vital role in improving the building's performance and primary energy. In BACS assessment, it is noted if any function is already installed in the building, or it can be installed or not. Simple BACS performance improvement index can be calculated by:

$$E_{BACS} = \frac{EP_0 - EP_i}{EP_0}$$

..............................Eq 10

Where,

EP_0 is the primary energy need for the building in the original state,

EP_i is the primary energy need for the building with the function improvement implemented.

4 Chapter 4: Application

In this chapter, the preliminary requirements and results from the research work will be discussed. Firstly, the selection of the building is done, and its classification is checked whether it is residential or non-residential building. Later the data is collected on the basis of methods discussed above in the methodology section. Then, all the inputs will be added to the software Edilclima EC 700 which includes the graphic input, stratigraphy of building, occupancy details, shading details, and systems data etc. The results are generated by the software, and it is compared with the actual measured primary energy data with the help of the calibration process.

After the calibration of the building energy model, EEMs will be applied to the components. Later, the deliverables will be provided to the TIMEPAC project for TDS 2. According to the TIMEPAC protocol (TIMPEPAC 2022b), the deliverables that have to be provided are the TEPA calibration, ECM assessment, IEQ assessment and BACS assessment. First, the whole case study and then primary results obtained of the building model without any calibration will be explained.

4.1 CASE STUDY

In this section, we will delve into a comprehensive case study of our research. We will explore the various parameters that played a significant role in our findings, each of which will be elaborated upon in the subsequent sections. The data regarding the stratigraphy and design of the building was provided along with the small details regarding the systems. Other data such as occupancy details, shadings and few properties of materials that were not provided was taken from the standards mentioned in the literature review. There were few changes done in the building such as such face bricks that were not mentioned in the design file provided, those were taken during the on-site survey of the building. The buildings measured energy consumption was provided from 2nd Jan to 7th of April in which the data in 1st Jan and 8th of April were incomplete. All the data that is collected or added to the software for the simulation is described in the following headings.

4.1.1 REFERENCE BUILDING

The building under consideration lies in Torino, Italy. It is a residential building located in Via Antonio Pigafetta 52, Torino. It lies in the category of E.1 (1) under the DPR 412/93 category. The reference building is surrounded by other residential buildings of the same height or more. The information on the number of occupants in the building is not provided. After the site visit of the building, it was discovered that some changes have been done to the stratigraphy that are not available in the original plan.

By looking at the floor plan of the building, there is a common area on each floor except the top floor from where there is a corridor that leads to different apartments. The apartments range from 38 m^2 to 41 m^2. The stratigraphy, systems, and occupancy details of the building will be discussed in the following section. The plan of the building is obtained from the Revit software which shows the following characteristics of the building shown in Figure 24 and Figure 25

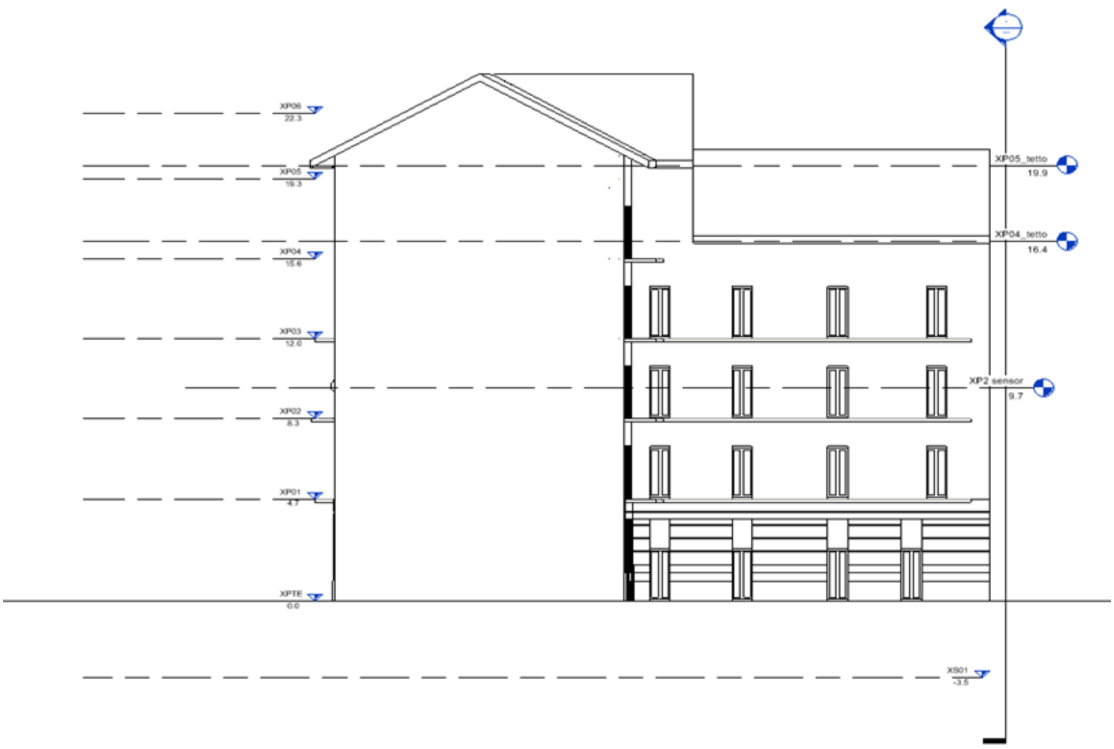


Figure 24 Elevations of building from North

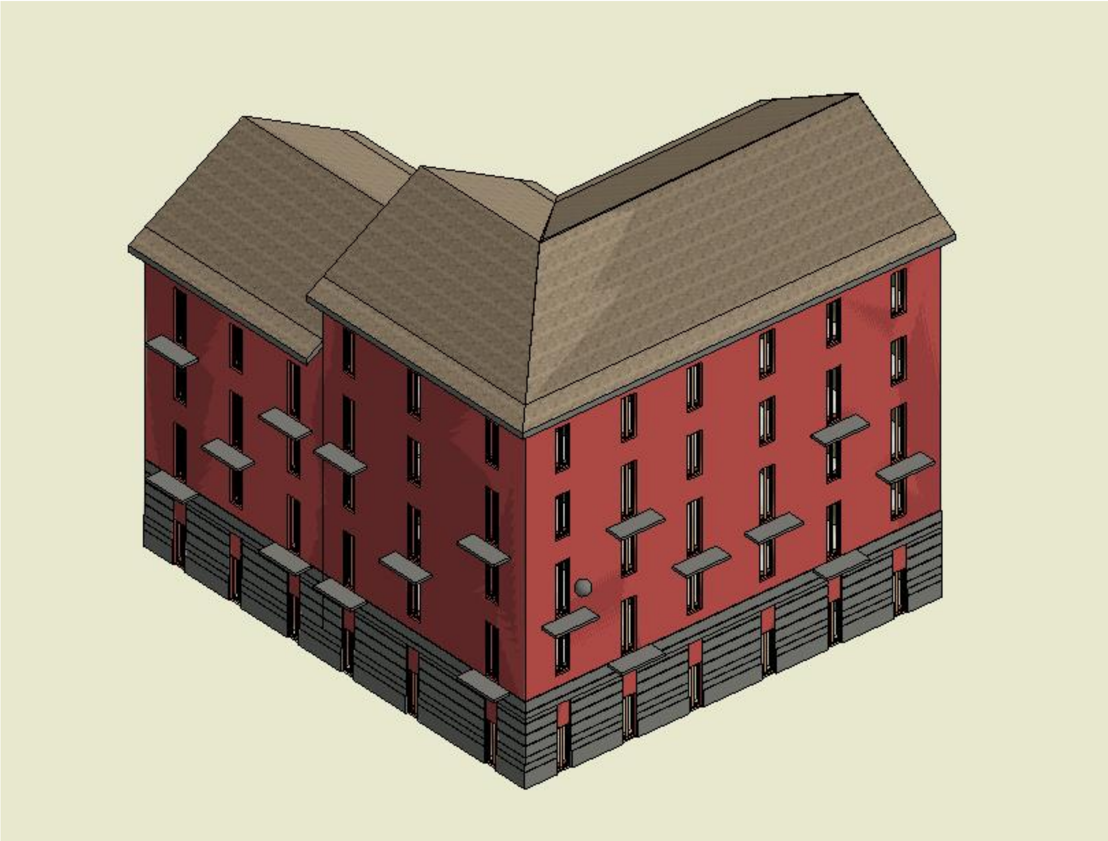


Figure 25 3D view of building in Revit

After looking at Figure 24, it can be seen that the building has total no of 5 floors on the East facing facade while there are total of 4 floors on the other side. The 5th floor is the unconditioned floor as known as the sunroom. The roof is pitched while there are the face bricks on the outer facade of the building. The total height of the building is around 22.3 m while height of the floor's changes. The ground floor of the building has different stratigraphy of walls as compared to others while some of the windows have the balconies. Figure 26 illustrates the building after visiting the site. The window on the floors uses the shutters. It shows that the two buildings are attached as one unit, and some changes are implemented on the facade of the building that is not available in the Revit model. Also, it shows that the residential building is under use.

Figure 26 Building under research

4.1.1.1 ENERGY PERFORMANCE

To perform the energy performance calculation of the building, the following are the steps that are done in Edilclima EC700. EC700 allows us to calculate the energy performance of buildings both with a monthly method according to UNI/TS 11300 and with a dynamic hourly method according to UNI EN ISO 52016-1. The expected output of the simulation is the primary energy consumption and the emissions of the CO_2 of the building under focus. As explained before that the simulation will run only for the period of 2nd Jan to the 7th of April. The energy per square meter of the floor area is calculated by the means of the simulation. For the purpose of the research each and every data as input is added carefully and simulation is performed for the climatic data of the year of the measured data. In the following headings, each step are described that are used for the simulation of the model of reference building.

4.1.2 STEP 1: DATA COLLECTION

The first step is the data collection of the building. In this step, multiple parameters are filled in the general data of EC700 to proceed with the simulation. As mentioned before that the data has been taken from the reliable sources and the design provided. In the following headings the climatic data, buildings envelope data, occupancy data, shadings data and the systems are discussed briefly. Some of the reference building parameters has been discussed above that will be used in the graphic input. The building lies in the latitude of 45˚7' and the longitude of 7˚ 43'. Currently, all of the data collected is according to the typical meteorological year 2016 as the measured data is for the corresponding year.

4.1.2.1 CLIMATIC DATA

The climatic data is obtained by EC700 according to UNI 10349:2016 for Torino municipality and province such as external temperature, solar irradiation, pressure and wind etc . A typical meteorological year (TMY) is a set of meteorological data with data values for every hour in a year for a given geographical location. The data is in the (. epw) format and can be used by building simulation software The typical meteorological year is used for the analysis of the building while 2016 is used for the calibration process. In this case, we have data from 2nd Jan to 7th April of 2016, so the last week will have 6 days instead of 7. Figure 27 shows the climatic data of the Torino municipality.

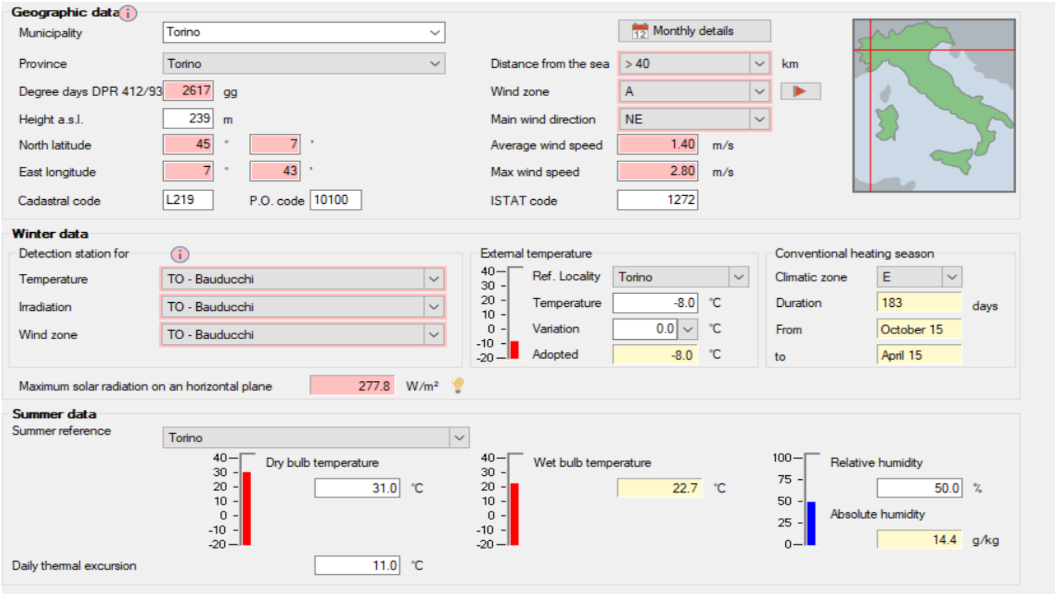


Figure 27 Climatic Data

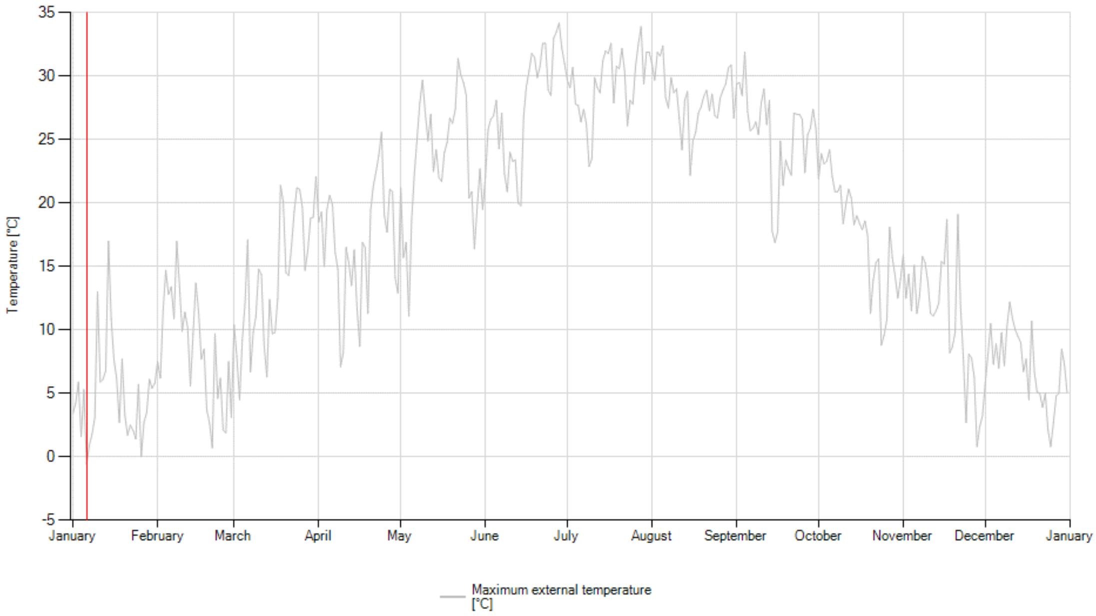


Figure 28 Outdoor temperature of Turin

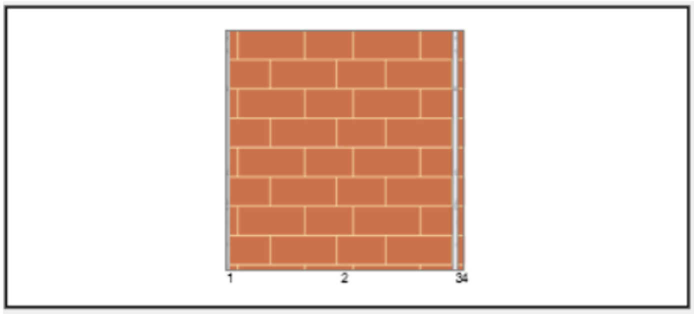
Upon analysing the graph (Figure 28), one can infer that Turin experiences its peak temperatures during July and its lowest temperatures in January. Heating is essential from 15 October through 15 April, whereas June, July, and August demand cooling. The maximum solar radiation on a horizontal plane is measured as 227.8 W/m^2.

4.1.2.2 BUILDING ENVELOPE DATA

In this section, the stratigraphy and the graphic plan of the building will be discussed. The building is comprised of external/internal walls, floors, ceilings/roofs, windows, and thermal bridges. Each component has a certain thermal transmittance that describes how much heat passes through it. There are certain standards under which the U value of the component should be under the limits to have a higher efficient building. If the U value of a component is higher that means more of the heat passes through it from or to the external environment which in turn increases the demand for the cooling or heating required. So while designing the building, it should be kept in mind to keep the components U value under the limits defined by references mentioned in literature review. Some of the properties of materials and stratigraphy that were not provided by the documentations, were taken from UNI/TR 11552:2014 (UNI, 2014) and EN ISO 10456:2007 (Standardization, 2007). The specific heat, dry and wet vapor pressure has been taken from the same standards

4.1.2.2.1 WALL

The external wall from conditioned to unconditioned space comprises of stratigraphy as shown in Figure 29 :



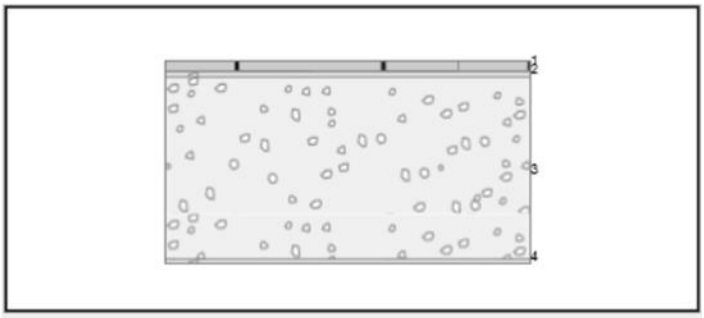
Nr	Description	Thickness [mm]	Cond. [W/mK]
1	PLASTER	10.00	0.400
2	T06_brick_01	590.00	0.551
3	PLASTER	10.00	0.400
4	Solid Exposed Face Bricks	20.00	0.650

Figure 29 External wall stratigraphy

It has the U-value of 0.739 W/m^{2}K which is quite higher than the limit that is 0.26 W/m^{2}K. The internal wall is made up of 2 layers of plaster and wall bricks.

4.1.2.2.2 FLOOR

The basic stratigraphy of the floor is as follows Figure 30:



Nr	Description	Thickness [mm]	Cond. [W/mK]
1	Piastrelle in marmo	25.00	3.000
2	PLASTER	10.00	0.400
3	CONCERETE FINAL	375.00	1.150
4	PLASTER	10.00	0.400

Figure 30 Stratigraphy of floor

The U-value of different types of floors are as follows in Table 5:

Table 5 U-value of floors

Floor	U value (W/m^{2}K)	U value (W/m^{2}K) limit
Basement	0.564	0.26
Ground	1.380	1.40
Normal	1.341	1.40

4.1.2.2.3 ROOF

The stratigraphy of the roof is as follows in Table 6:

Table 6 Stratigraphy of Pitched Roof

Code	Description	Thickness [mm]	Cond. [W/mK]	R [m²K/W]	M.V. [kg/m³]	H.C. [kJ/kgK]	V.R.
e1340	Tegole in terracotta	50.00	1.0000	0.050	2000	0.80	40
u112	PLASTER	10.00	0.4000	0.025	1000	1.00	10
e10	Closed air layer Av<500 mm²/m	20.00	0.1250	0.160	-	-	-
u110	CONCERETE FINAL	240.00	1.1500	0.209	1800	1.00	100
u112	PLASTER	10.00	0.4000	0.025	1000	1.00	10

The U value of the pitched roof is 1.563 W/m^{2}K while the limit is 1.40 W/m^{2}K.

4.1.2.2.4 WINDOWS

There are two different windows that are used in the building. Window 1 has the single glazing and the total area of 3.153 m^2 while the window 2 has the single glazing with the area of 2.552 m^2. Both of them have a U value of 3.5 W/m^2K which is quite high. The information regarding the dimensions and U-value of the windows are taken from the provided Revit model. The windows use the white venetian curtain and There are also shutter used in front of the rooms on the ground floor that has glass doors. The total area of the glazing is 245.79 m^2 while the window to wall ratio for the building is 9.05%.

4.1.2.2.5 THERMAL BRIDGE

The thermal bridges applied on the model are of Roof, Corner between walls, Wall-Pillar, Wall-Internal Wall, Wall- Slab on the ground, Wall- Balcony, and wall frame calculated through the EC 709 with reference of UNI EN ISO 14683:2017 and UNI EN ISO 10211:2018 (UNI, 2018) . Figure 31 shows the addition of the thermal bridges to the first floor. By the same way it has been added to the whole building. The thermal bridges for the components are selected on the basis of its specifications, inclusion of the external or internal insulation or the orientation of the component. These thermal bridges are later checked if there is a risk of the mold formation or not.

4.1.2.3 SHADINGS/OCCUPANCY

The shadings in the windows above are white Venetian curtains. There is no fixed schedule noticed due to the change in use of different occupants so standard values are used for the schedule.

Table 7 Schedule of curtains for weekdays

Hours of the day	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
North	√	√	√	√	√	√	√	√	√	√	√	-	-	-	√	√	√	√	-	√	√	√	√	√
North-East	√	√	√	√	√	√	√	-	-	-	-	-	-	-	-	-	-	-	√	√	√	√	√	√
East	√	√	√	√	√	√	√	-	-	-	-	-	-	-	-	-	-	-	√	√	√	√	√	√
South-East	√	√	√	√	√	√	√	-	-	-	-	-	-	-	-	-	-	-	√	√	√	√	√	√
South	√	√	√	√	√	√	√	-	-	-	-	-	-	-	-	-	-	-	√	√	√	√	√	√
South-West	√	√	√	√	√	√	√	-	-	-	-	-	-	-	-	-	-	-	√	√	√	√	√	√
West	√	√	√	√	√	√	√	-	-	-	-	-	-	-	-	-	-	-	√	√	√	√	√	√
North-West	√	√	√	√	√	√	√	-	-	-	-	-	-	-	-	-	-	-	√	√	√	√	√	√
Horizontal	√	√	√	√	√	√	√	-	-	-	-	-	-	-	-	-	-	-	√	√	√	√	√	√

Table 8 Schedule of curtains for weekends

Hours of the day	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
North	√	√	√	√	√	√	√	-	-	-	-	-	-	-	-	-	√	√	√	√	√	√	√	√
North-East	√	√	√	√	√	√	√	-	-	-	-	-	-	-	-	-	√	√	√	√	√	√	√	√
East	√	√	√	√	√	√	√	-	-	-	-	-	-	-	-	-	√	√	√	√	√	√	√	√
South-East	√	√	√	√	√	√	√	-	-	-	-	-	-	-	-	-	√	√	√	√	√	√	√	√
South	√	√	√	√	√	√	√	-	-	-	-	-	-	-	-	-	√	√	√	√	√	√	√	√
South-West	√	√	√	√	√	√	√	-	-	-	-	-	-	-	-	-	√	√	√	√	√	√	√	√
West	√	√	√	√	√	√	√	-	-	-	-	-	-	-	-	-	√	√	√	√	√	√	√	√
North-West	√	√	√	√	√	√	√	-	-	-	-	-	-	-	-	-	√	√	√	√	√	√	√	√
Horizontal	√	√	√	√	√	√	√	-	-	-	-	-	-	-	-	-	√	√	√	√	√	√	√	√

In Table 7 and Table 8 , the curtains are opened during the day to let the sunlight come inside and so decrease the heating energy required.

4.1.2.4 GRAPHIC INPUT

Following the parameter input in EC700, the next step involves incorporating the generated IFC file into EC700 to produce a layout for the building's floors. This layout includes the addition of various building components and the specification of room heights in meters. Finally, the thermal bridges are integrated into the layout to complete the process.

Figure 31 Graphic layout of the first floor

The Figure 31 illustrate the graphic layout of the first floor of the reference building. It can be seen that the different thermal bridges are added. There are apartments with the corridor and the common space. Some of the windows have the balcony. The influence of surrounding buildings as obstacles to energy consumption is very crucial. To account for this impact, I have included shaded areas representing nearby structures in the Figure 32. It is evident from the illustration that some of these neighbouring buildings surpass our reference building in height, while others are lower. During the process of rendering of the solar radiation, it is evident that the other buildings cast the shadow on the reference building. Consequently, this shadowing effect leads to an increased demand for heating, particularly noticeable on the western and northern facades, which are entirely shadowed by the surrounding buildings. Figure 32 illustrates the obstacles around the building.

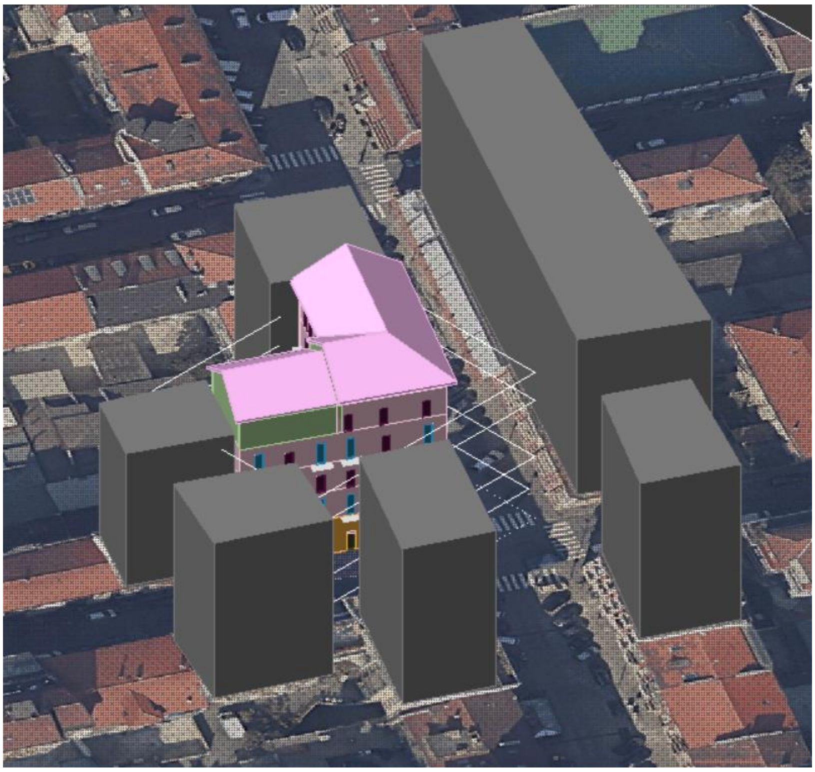


Figure 32 Shadings in building

4.1.2.4.1 ZONES

There are two types of zones either conditioned or non-conditions zones. The rooms are later added to conditioned or non-conditioned zones according to their position, function, and characteristics. There are 9 conditioned zones as mentioned in Figure 33. The 5th floor of the building is included in the non-conditional zone. Each zone has multiple spaces and the division of the zones in the building is done based on its orientation. While adding the zones to the model, the occupancy profile is added according to the

Nr.	DPR 412 category	Description	Net surf. [m²]	Gross Vol. [m³]
1	E.1 (1)	Zone 1	192.27	1311.63
2	E.1 (1)	Zone 2	177.85	1278.75
3	E.1 (1)	Zone 3	191.72	972.10
4	E.1 (1)	Zone 4	177.91	947.17
5	E.1 (1)	Zone 5	112.67	607.45
6	E.1 (1)	Zone 6	257.01	1336.42
7	E.1 (1)	Zone 7	191.67	971.87
8	E.1 (1)	Zone 8	177.96	947.41
9	E.1 (1)	Zone 9	249.59	1411.44

Figure 33 Zones data

4.1.2.4.2 SYSTEMS

The final phase of step 1 involves the integration of systems into the building. Given the absence of a cooling system in the current structure, the heating and domestic hot water (DHW) systems are incorporated into EC700. The district heating water substation, located in the basement, serves as the central source of hot water for heating the entire building. The hot water system operates autonomously, maintaining a supply temperature of 40 degrees Celsius. The daily hot water demand is standardized at 242 litres/day throughout all months for E.1 (1) building. Each apartment is equipped with a traditional boiler for hot water generation having the specification taken from ANNEX 1 :

Nominal Combustion Power= 2.81 kW (according to zones)

Useful efficiency = 90.7%

Water average temperature = 70 °C

Installation= Internal

Energy carrier= Methane.

The district heating substation provides the centralized flow to the building with a temperature set point operating profile. The radiators are placed on the internal wall with an emission efficiency of 95%. Figure 34 illustrates the emission system that is radiators in this case and the distribution systems. It illustrates the flow of water through the pipes and radiators.

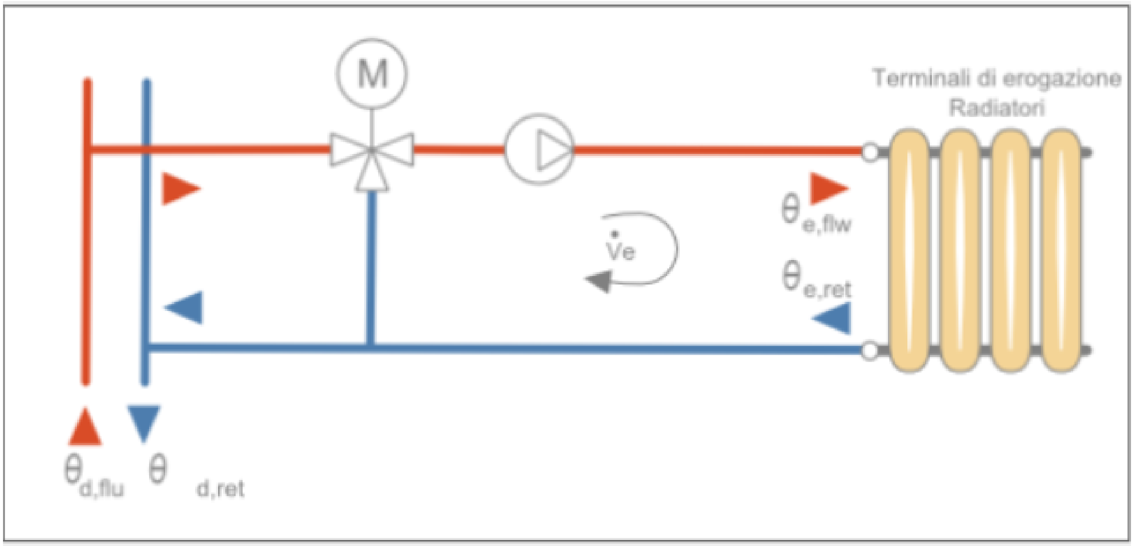


Figure 34 Flow diagram heating

4.2 PRIMARY RESULTS

After the addition of all the data including graphic inputs, occupancy details and systems, the first A3 evaluation has results as follows:

$Q_{H,sys,out}$ = 90809 kWh/year

$Q'_{H,gen,out}$ = 90561 kWh/year

$Q_{H,gen,out}$ = 101326 kWh/year

$Q_{H,gen,in}$ = 101979 kWh/year

$Q_{H,sys,out}$ is the energy ouput of the system while $Q_{H,gen,out}$ is the energy that is provided by the generator to the system. They both differ due to the losses in the systems. The $Q_{H,gen,in}$ is the energy that is provided to the generator. The total primary energy results are as follow as shown in Table 9:

Table 9 Primary energy data for non-calibrated

Service	**$Q_{p,nren}$ (kWh)**	**$Q_{p,ren}$ (kWh)**	**Q_{ptot} (kWh)**
Heating	107078	0	107078
Domestic Hot water	35715	36	35751
Global	142793	36	142829

$Q_{p,nren}$ is the primary energy consumption by non-renewables while $Q_{p,ren}$ is the primary energy consumption by renewables. Q_{ptot} is the total sum of both. The total consumption of methane is 13667 Nm^3/year and the total consumption of electrical energy is 77 kWhel/year. Now, I have to check if the consumption of the simulated model is complying with the measured data or not. In order to check that, we use indicators such as MBE and CV(RMSE). Measured data that is obtained from the data interpretation is as following Table 10:

Table 10 Measured and simulated energy consumption of building.

Weeks	**Days**	**Measured energy consumption of the building (kWh)**	**Simulated energy consumption of the building (kWh)**
1	7	4564.92	12887.10
2	7	4134.31	6738.24
3	7	5323.34	7388.25
4	7	4329.46	6513.32
5	7	3649.93	5011.46
6	7	3936.65	4445.37
7	7	3937.99	5743.11
8	7	2881.98	7190.65
9	7	3670.07	6479.38
10	7	3862.69	4087.89
11	7	3229.00	3919.67
12	7	1677.76	1348.65
13	7	1493.85	903.91
14	6	1305.84	365.53

The graphical method is comprised of the daily energy consumption on Y axis while daily outdoor temperature on X axis. The simulated and measured energy signatures are plotted with their trend-lines. Each point defines the energy consumption on certain temperature. The trend lines are later analyzed on the basis of their difference. By using the graphical method (Figure 35),

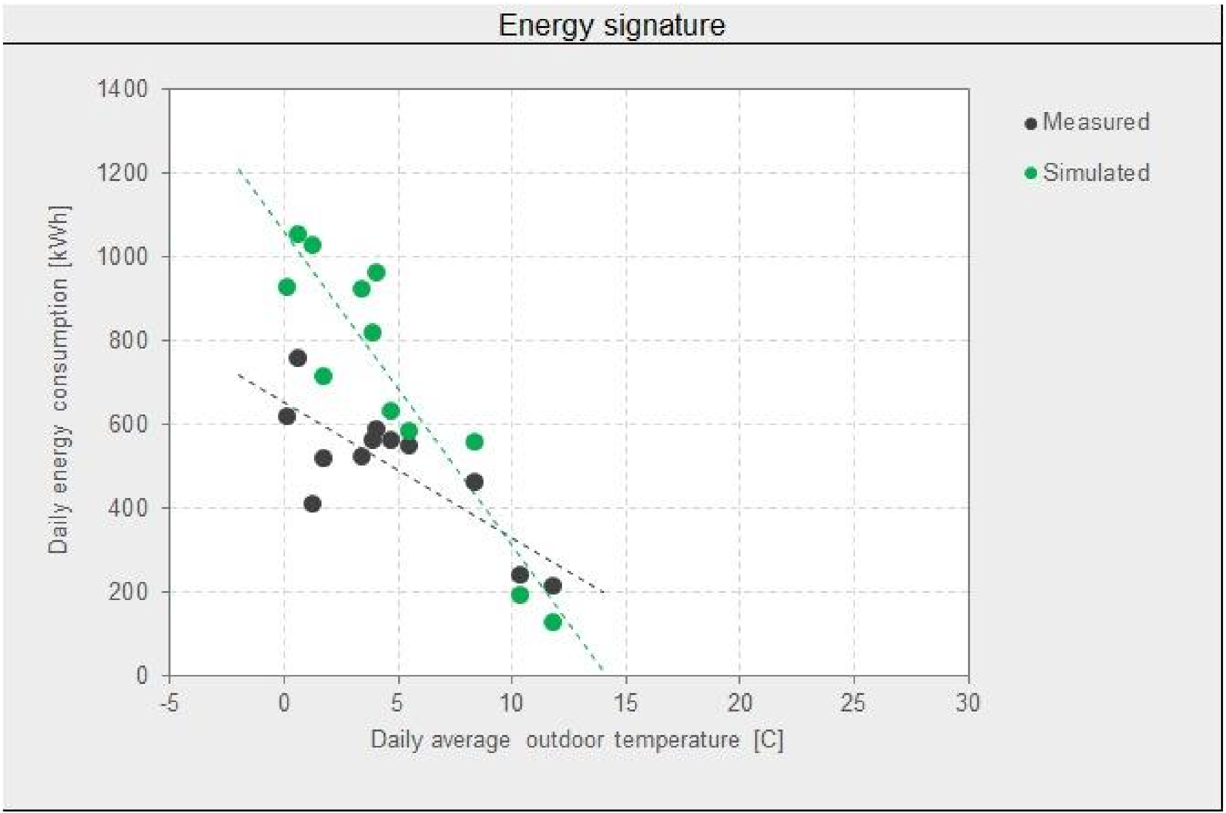


Figure 35 Energy signature for non-calibrated data

As it can be seen from the above graph that the simulated data is not calibrated and requires modifications. Simulated data has higher values in heating days as compared to the measured data. Also the MBE is 41.9% and CV(RMSE) is 57.3% that is not calibrated according to the ASHRAE guidelines 14 (ASHRAE, 2014). It can be seen that if there is a high difference in the trend line slopes then the difference between the indoor and outdoor temperature are the influencing factors. We require to modify the thermal properties of the building components, thermal bridges linear thermal transmittance, and/or ventilation/infiltration rates.

4.3 TEPA CALIBRATION

In order to calibrate the simulated model according to the measured data, there were multiple scenarios made. Each scenario was analyzed to see if the MBE is under the limits or not. There were multiple scenarios in which MBE was satisfied but CV(RMSE) not and vice versa. The problem is the guidelines are set to hourly or monthly values. There are no specific limit values for the weekly data. Table 11 describes the changes that are done to the simulated model for best calibration:

Table 11 Difference between calibrated and non-calibrated data

Sr.No	Paramteters	Non-Calibrated	Calibrated
1	**Ventilation rate**	0.30 (Vol/h)	0.15 (Vol/h)
2	**Occupancy factor**	Not according to standards	According to EN ISO 16798-1:2019
3	**Thermal properties of building components**	Change in the U value of the windows from 3.275 W/m^2K to 2.437 W/m^2K. Addition of shutters to the ground floor.	
4	**Thermal bridges**	Addition of the thermal bridge related to the pillars	
5	**Control**	Change of the control from autonomous to automated	

After the implementation of the above measures, the following are the values obtained.

QH,sys,out= 112898 kWh/a

Q'H,gen,out= 112436 kWh/a

QH,gen,out= 139167 kWh/a

QH,gen,in= 140476 kWh/a

The total primary energy results are as follow:

Table 12 Total primary energy results for calibrated data

Service	Qp,nren (kWh)	Qp,ren (kWh)	Qptot (kWh)
Heating	147499	0	147499
Hot water	35703	1887	37591
Global	183203	1887	185090

The total consumption of methane is 16803 Nm^3/a, and the total consumption of electrical energy is 4016 kWhel/a.

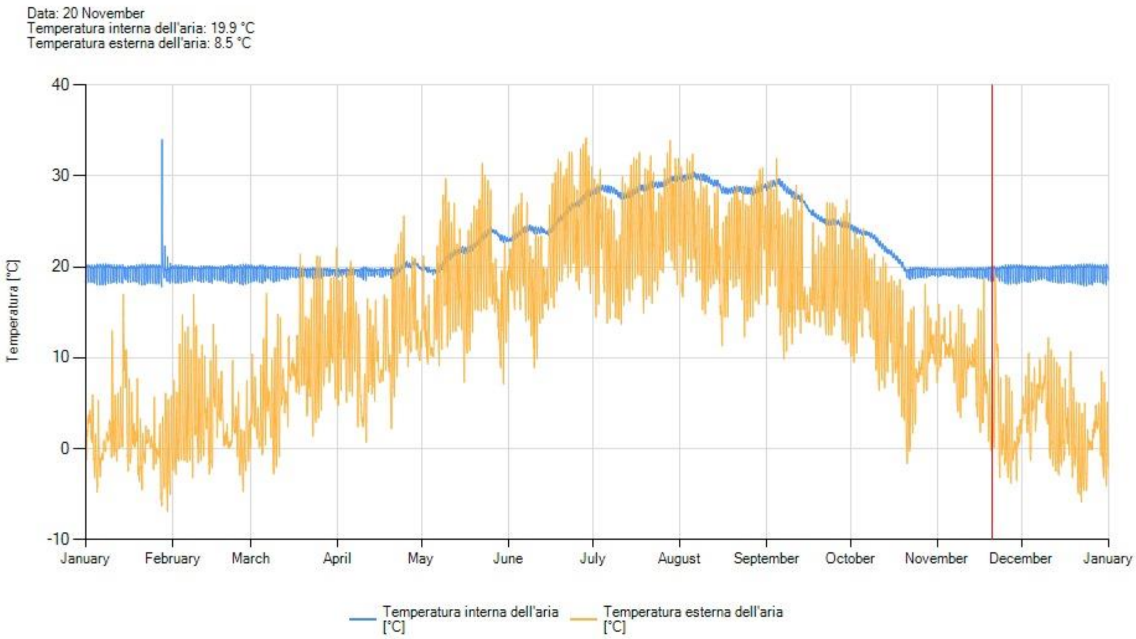


Figure 36 Internal temperature to external temperature of air building

The above graph (Figure 36) shows that the internal temperature is under the standard range in the days of winters and summers.

By using the graphical method,

Table 13 Measured and Simulated data

Measurement period				Measured data		Simulated data	
Start [m/d/y]	End [m/d/y]	n of days [-]	Daily av. outdoor t. [°C]	Energy consumption [kWh]	Daily energy consumption [kWh/d]	Energy use [kWh]	Daily energy consumption [kWh/d]
09/01/2016	15/01/2016	7	4.1	4134	591	5251	750
16/01/2016	22/01/2016	7	0.6	5323	760	5482	783
23/01/2016	29/01/2016	7	0.1	4329	618	5003	715
30/01/2016	05/02/2016	7	1.8	3650	521	3128	447
06/02/2016	12/02/2016	7	4.7	3937	562	3087	441
13/02/2016	19/02/2016	7	3.9	3938	563	4148	593
20/02/2016	26/02/2016	7	1.2	2882	412	5268	753
27/02/2016	04/03/2016	7	3.4	3670	524	4749.275024	678
05/03/2016	11/03/2016	7	5.5	3862.690355	552	2950.741468	422
12/03/2016	18/03/2016	7	8.4	3229.002797	461	2737.150164	391
19/03/2016	25/03/2016	7	10.3	1677.76303	240	872.7541223	125
26/03/2016	01/04/2016	7	11.8	1493.84591	213	536.0283967	77

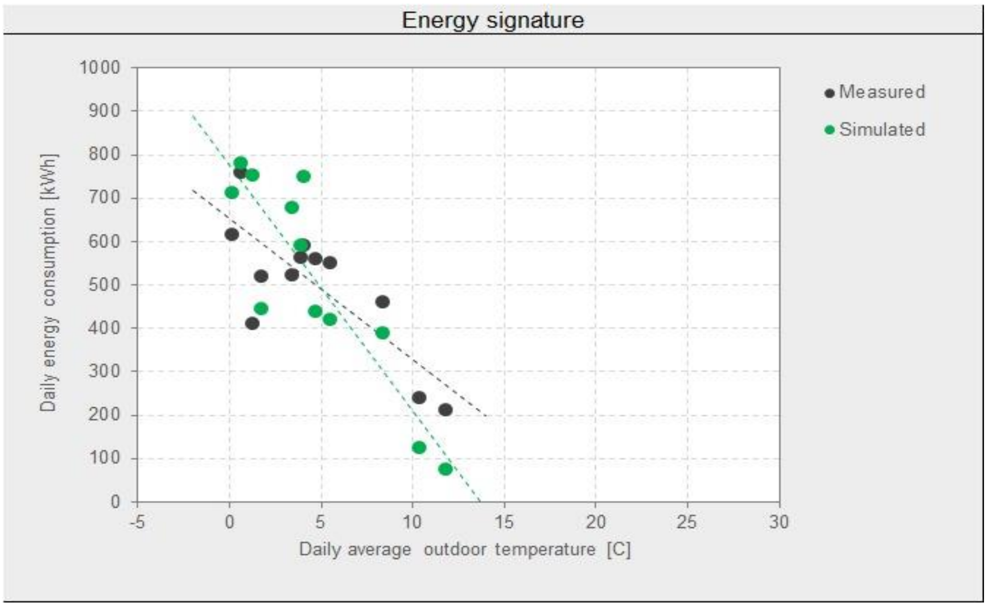


Figure 37 Energy signature of calibrated data

The graph above (Figure 37) demonstrates a relatively close alignment between the trend lines of the simulated data and the measured data, although they are not perfectly identical. The simulated and measured data are mentioned in Table 13. While the Mean Bias Error (MBE) is within acceptable limits at 2.6% according to both range for hourly and monthly data, the Coefficient of Variation of Root Mean Square Error (CV(RMSE)) is lower than the acceptable threshold for hourly data i.e., 30% but higher than the monthly threshold that is 15%, standing at 28.8%.

Several potential reasons for this data deviation can be identified:

1. The dataset spans only 12 weeks, limited to the period from January to April. A larger dataset could lead to closer alignment between the curves.

2. The lack of detailed information about occupancy patterns may contribute to the use of standard assumptions, introducing some deviation.
3. The focus on winter days in the dataset might lead to increased deviation.
4. Standards are provided for hourly data not for weekly data.

Considering that the current calibration represents the best achievable performance without compromising standards, it is advisable to utilize the existing model for the deliverables. In the following headings the deliverables of the research work will be mentioned.

4.4 ECM ASSESSMENT

As mentioned above in chapter 1, in ECM assessment we use multiple energy efficiency measures such as active and passive to the building to increase the energy classification. The list of the energy efficiency measures has been mentioned in Table 2. We defined the EEMs by only looking at the energetic aspects for this research by not considering some Italian legislations for example the addition thermal insulation on the external wall is not allowed according to current Italian legislation. The implementation of energy efficiency measures was for research purpose on international level so the national laws for some of the measures were neglected due to irrelevance from the energetic point of view of them. As mentioned in the literature review, multiple researchers used external thermal insulation as it provided one of the best results, external insulation is added to this research work in order to compare and analyze on international level. In the following paragraphs, multiple scenarios will be discussed in detail along with the cost breakdown. There is one another important information that the simulations for this section, IEQ assessments and BACS assessments are performed for 2023.

4.4.1 SCENARIO 1

In this scenario, external wall thermal insulation is added to the stratigraphy. The U-value of the external wall (unconditioned to external, conditioned to external) was not under the provided limits. So, in this scenario the expanded polystyrene (EPS 250) has been added to the wall with air cavity of Av< 500 mm^2/m. Rest of the stratigraphy is the same. By using such a technique, the U-value of the wall is decreased to under 0.157 W/m^{2}K that is under the limits i.e., 0.28 W/m^{2}K (D.M.26 June 2015). The new stratigraphy of the wall is as shown in Table 14:

Table 14 Stratigraphy of wall

MATERIAL	THICKNESS (mm)
Plaster	10
Brick	590
Air cavity	50
Expanded polystyrene (EPS 250)	160
Plaster	10
Solid exposed brick walls	20

Table 15 shows the price breakdown of each component added and the other costs.

Table 15 Cost breakdown for scenario 1

EXTERNAL WALL	
Area	2288.52 m^2
Working hours	120 h
Expanded polystyrene EPS 250 (160mm thickness)	34.32 €/m^2
Labor	30.71 €/h
Number of labors	3
Total EPS Cost	78542€
Labor Cost	11055.6 €
Total Cost	89597.60 €

All the prices above have been taken from "Prezzario della Regione Piemonte 2023", (PIEMONTE, 2023) Before using the new costs, some certain parameters that need to be discussed are the interest rates, calculation periods and others. So,

Interests rate= 4% (YCharts, 2023)

Calculation periods= 30 years

Conditioned floor area= 1728.65 m^2

Electricity cost= 0.2063 €/kWh (countryeconomy, 2023)

Methane cost = 0.767 €/Sm^3 (Statistica, 2023)

After the input of the above parameters, the electricity and methane yearly increment costs are calculated. These costs are used for the calculation of NPV and DPP. To make a comparison of each scenario, we have the baseline in which the annual costs of electricity and natural gas are calculated.

For scenario 1, the total investment costs are 89597.60 € with no maintenance cost or replacement costs as it is replaced after 30 years. The annual energy carrier cost is calculated as 6649 € while the NPV in euros is 218282.9. The NPV is 126.3 €/m^2 while the DPP is 10 years. This means that after 10 years we will have a positive NPV and the profit from the investment.

4.4.2 SCENARIO 2

In this scenario, the roof thermal insulation is added to the building. The roof of the building is pitched and has very high U value. Therefore, insulation is added to decrease the thermal transmittance through the roof. The new roof has the following stratigraphy as shown in Table 16:

Table 16 Stratigraphy of roof

MATERIAL	**THICKNESS (mm)**
Rooftiles	50
Plaster	10
Expanded sintered polystyrene (with graphite)	160
Air cavity (Av<500 mm^2/m)	20
Concrete	240
Plaster	10

Table 17 shows the price breakdown of each component added and the other costs.

Table 17 Cost breakdown for scenario 2

ROOF	
Area	597.74 m^2
Working hours	60 h
Expanded sintered polystyrene (with graphite) (160 mm thickness) price	38.17 €/ m^2
Plaster price	16 €/ m^2
Number of labors	2
Total material cost	32379.41 €
Labor cost	3685.2 €
Total cost	36064.61 €

The U-value of the roof decreased to 0.1777 W/m^2K. After the calculation, it is found out that the total annual cost of electricity and natural gas is 13660 €/a. The NPV is 7248.1 € and 4.2 €/m^2. The DPP for this investment is 30 years that is very big. The life of the EEM 2 is 30 years, so it is not a good investment.

4.4.3 SCENARIO 3

In this scenario, insulation to the ground floor is added to decrease the thermal transmittance from the ground floor to the basement. The new stratigraphy of floor is as follows in Table 18:

Table 18 Stratigraphy of floor

MATERIAL	THICKNESS (mm)
Internal flooring stoneware	25
Cement mortar	30
Expanded sintered polystyrene (EPS 250)	160
Plaster	10
Concrete	375

The U-value of the floor decreased to 0.179 W/m^{2}K that is lower than the limit that is 0.28 W/m^{2}K (D.M.26 June 2015). Table 19 shows the price breakdown of each component added and the other costs.

Table 19 Cost breakdown for scenario 3

FLOOR	
Area	1181.5 m^2
Working hours	72 h
Expanded polystyrene EPS 250	34.32 €/m^2
Internal flooring stoneware	40 €
Labor	30.71 €/h
No of labors	2
Total EPS Cost	87809.08 €
Labor Cost	4422.24 €
Total Cost	92231.32 €

After the calculation, it is found out that the total annual cost of electricity and natural gas is 11297 €/year. The NPV is 40247.8 € and 23.3 € /m2. The DPP for this investment is 25 years that is still big.

4.4.4 SCENARIO 4

In this case, the replacement of the windows with ones with better thermal properties is analyzed. As, windows have the 9.05% window to wall ratio, we need to decrease the thermal transmittance through it. In the new windows, the 4-6-4-6-4 with argon gas is used that has the thermal transmittance of 1.1 W/m^{2}K than is lower than the limit that is 1.40 W/m^{2}K (D.M.26 June 2015). The triple glazing glass is used instead of the single glazing that is already used. The transmittance of the windows on the ground floor is kept the same as they have the shutters on the outside. The cost breakdown for scenario 4 is shown in Table 20.

Table 20 Cost breakdown for scenario 4

WINDOWS	
Area	195.3 m^2
Working hours	24 h
Tripple glazing	110 €/m^2
Labor	30.71 €/h
No of labors	2
Total glass cost	21483 €
Labor cost	1474.08 €
Total cost	22957.08 €

After the calculation, it is found out that the total annual cost of electricity and natural gas is 14413 €/year. The NPV is -8073.7 € and -4.7 €/m^2. The DPP for this investment is more than 30 years. The life of the EEM 4 is 30 years so this investment is not sustainable.

4.4.5 SCENARIO 5

After the implementation of the passive EEMs, the first active energy efficiency measure that is added to the building is the installation of DHW with high efficiency technology. The traditional were used to provide hot water in the building and instead of it the heat pumps are used that have higher efficiency. The current heat pump is BAXI/SPC/SPC 300 (details in annex 1) that has a capacity of 270 liters. It has a COP of 4.72 and energy efficiency of 161%. The electrical auxiliary power is 450 W and the cut off temperature is 10 degrees Celsius.

Table 21 describes the cost breakdown of the EEM 8.

Table 21 Cost breakdown for scenario 5

HEATPUMP	
No of Baxi	9
BAXI Price	2900 €
Labor Hours	10
No of labor	1
Labor Wage	30.71 €
Total BAXI Price	26100 €
Total Labor	307.1 €

After the calculation, it is found out that the total annual cost of electricity and natural gas is 12825 €/year. The NPV is 30930.4 € and 17.9 €/m^2. The DPP for this investment is 18 years. The life of the EEM 8 is 20 years so this investment is sustainable.

4.4.6 SCENARIO 6

The scenario 6 is the combination of scenario 1 to 4. The total cost for this investment is 240851 €. After the implementation of scenario 6, the NPV is 153203.6 € and 88.6 €/m^2. The DPP is 20 years, so this investment is possible.

4.4.7 SCENARIO 7

Scenario 7 is the combination of scenario 1 to 6. The total cost for this investment is 267258€with the maintenance cost of 150 €. After the implementation of the scenario 7, the NPV is 169178.8 € and 97.9 €/m^2. The DPP is 20 years, so this investment is possible.

4.4.8 SCENARIO 8

In scenario 8, EEM 12 (PV panels) and 14 (Controls systems) are added to scenario 7. There is an installation of photovoltaics and control systems in the building. The solar panels of SOLSONICA/Moduli S612 BI/S612 BI 280 (details in annex 2) have the capacity of

275 Wp (Watts peak power) per module. There are 68 modules used with a total potential 18700 Wp. The efficiency of single module is 0.16 with fpv (efficiency factor) 0.70. The gamma angle (Azimuth angle that is PV array's east–west orientation in degrees of the panels is 29.4 degrees while the beta (the tilt angle from the surface of the roof of PV panels) is 30 degrees. The panels are attached to the pitched roof of the building. The panels are installed on the south side of the building. Table 23 shows the cost breakdown of EEM 12 and 14. Table 22 describes the total cost of the photovoltaics used for the scenario 8.

Table 22 Cost breakdown for PV

PV	
Total power	18700 W
Price	1.1 €/W
Total price	20570 €

The current building complies with all the Italian legislations for NZEB as shown in Figure 38.

Tipo di verifica	Esito	Valore ammissibile		Valore calcolato	u.m.
Verifica termoigrometrica	Positiva				
Verifica sulla temperatura critica interna del ponte termico	Positiva				
Area solare equivalente estiva per unità di superficie utile	Positiva				
Coefficiente medio globale di scambio termico per trasmissione (H't)	Positiva				
Indice di prestazione termica utile per riscaldamento	Positiva	98.30	>	45.17	kWh/m²
Indice di prestazione termica utile per il raffrescamento	Positiva	5.95	>	5.82	kWh/m²
Indice di prestazione energetica globale	Positiva	152.45	>	73.13	kWh/m²
Efficienza media stagionale dell'impianto per servizi riscaldamento, acqua calda s...	Positiva				

Dettagli - Verifica termoigrometrica

Verifica termoigrometrica delle strutture opache

Cod.	Tipo	Descrizione	Condensa superficiale	Condensa interstiziale
M6	T	MAIN WALL CONDITIONED TO EXT...	Positiva	Positiva
M8	U	MAIN WALL UNCONDITIONED TO C...	Positiva	Positiva
M9	T	1st floor wall	Positiva	Positiva
P2	U	FLOOR GROUND	Positiva	Positiva
S1	U	ROOF FOR UNCONDITIONED	Positiva	Positiva

Figure 38 NZEB building

The total price of scenarios 6 that has EEM 1, 2, 3, 4, 6, 12, and 14 is 287828 € with maintenance cost of 650 €. The control systems are added to the building with the price of 4000 €. After the implementation of scenario 8, the NPV is 194673.1 € and 112.6 €/m^2. The DPP is 19 years that is under 20 years, so this investment is sustainable.

4.4.9 TOTAL

There are a total of 8 scenarios and now we will analyze the comparison between each scenario and choose the best one for the refurbishment. Table 23 shows that the lowest DPP is of scenario 1 and the highest is of scenario 4. In scenario 1 only, the building is not compliant with the Italian standard of NZEB. Below graphs show the comparison between the NPV (Net present value) and the DPP (Discounted Payback Period) of all the scenarios.

Table 23 NPV and DPP of total scenarios

	NPV (€/m^2)	DPP (a)
Scenario 1	126	10
Scenario 2	4	30
Scenario 3	23	25
Scenario 4	-5	>30 years
Scenario 5	18	18
Scenario 6	89	20
Scenario 7	98	20
Scenario 8	113	19

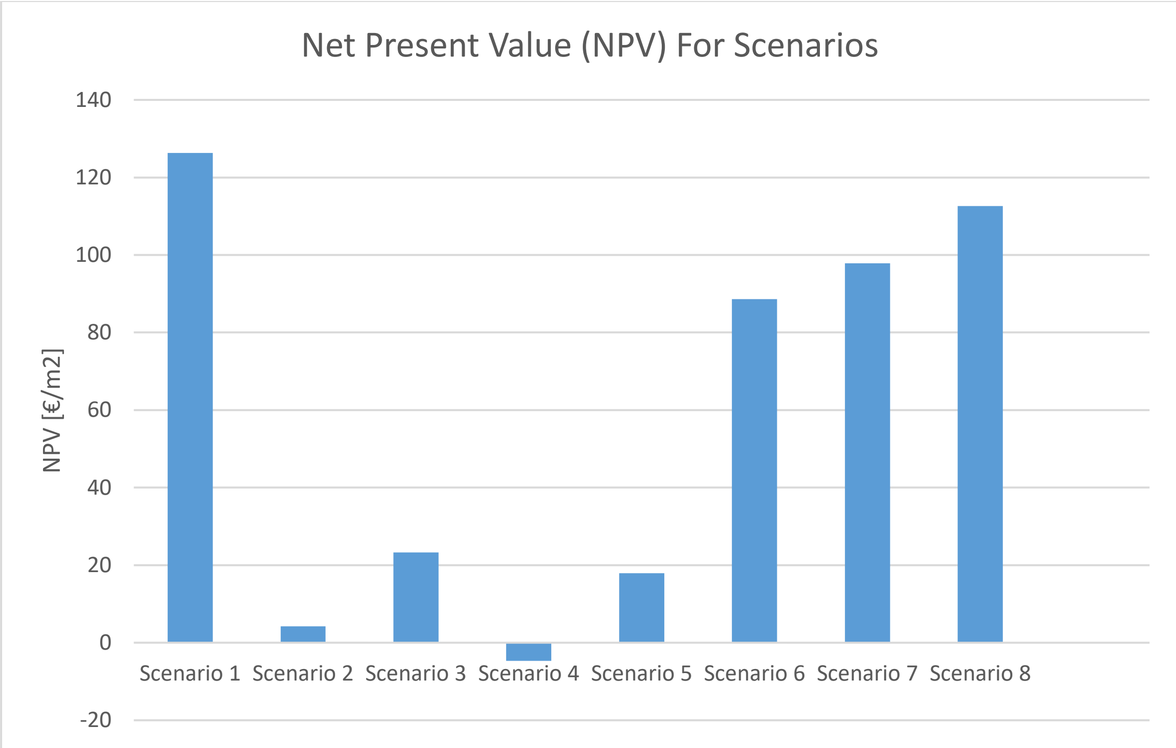


Figure 39 Net present value for all the scenarios

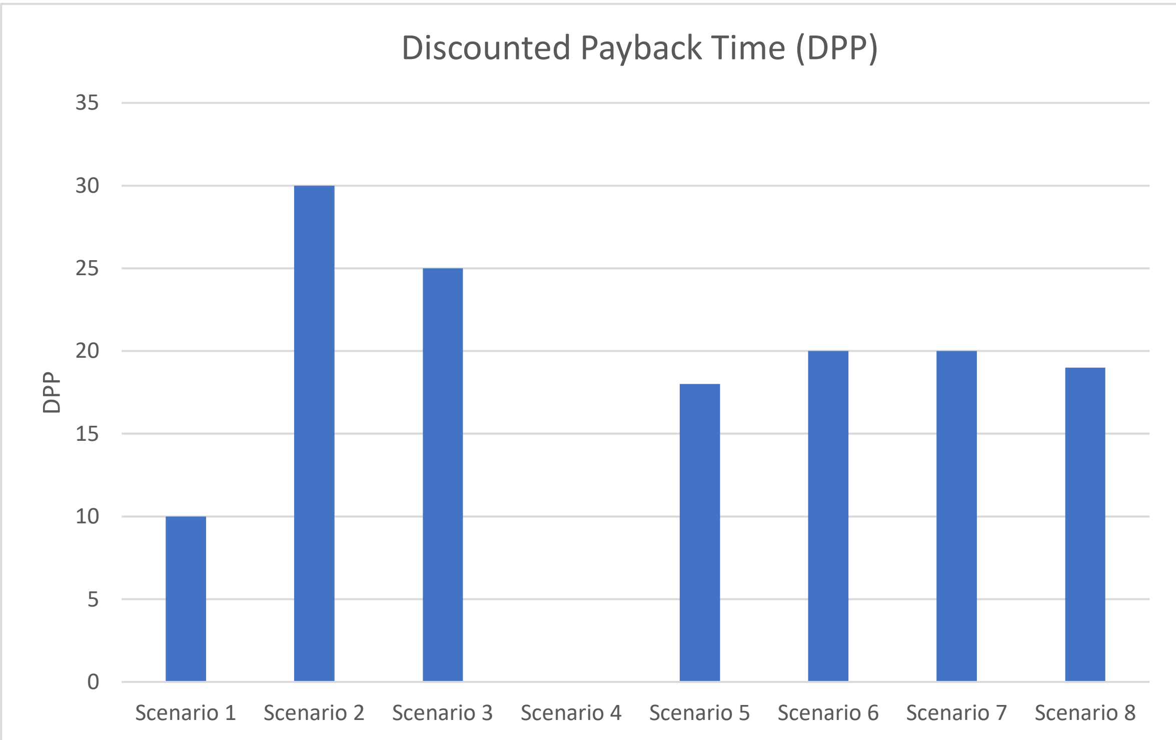


Figure 40 Discounted payback time for all scenarios

Figure 39 and Figure 40 shows that the best economic scenario is 1 with NPV and DPP. The insulation on the external wall of the facade will be done to increase the energy classification to A2.Figure 41 depicts the energy classification when only EEM 1 is applied to the model.

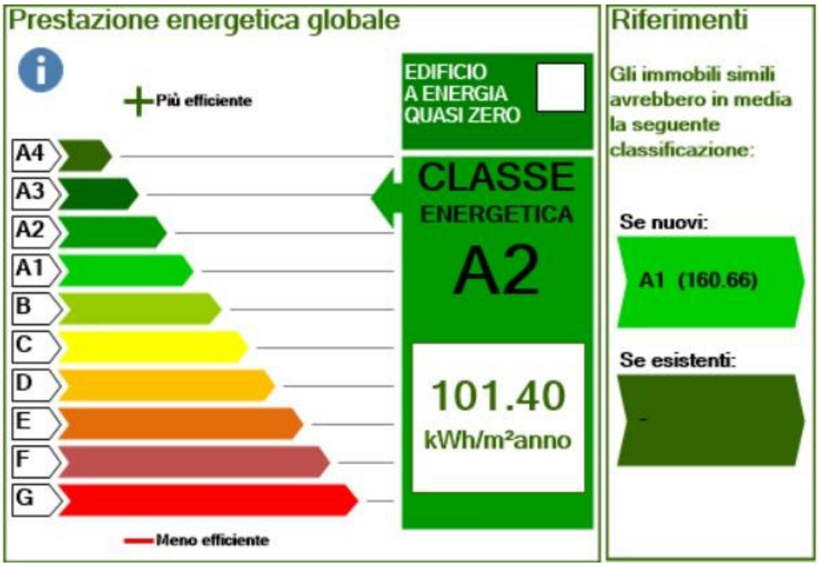


Figure 41 Energy classification with implementation of EEM 1

While with scenario 8, the NZEB is achieved with the energy classification of the A4 and primary energy consumption of 55.61 kWh/m^2 year.

4.5 IEQ ASSESSMENT

As IEQ assessment is divided into two parts such as thermal comfort and the indoor air quality assessment, so following headings describe the results of multiple assessments. These parts have been defined before in the methodology section. Room 11 in zone 3 has been chosen for the IEQ assessment. While the occupancy hours and indoor operative temperature for the thermal comfort analysis is taken from the zone 1 data. The level of thermal comfort or discomfort for the occupants will be analyzed on the basis of the comfort and discomfort hours. For indoor air quality assessment, it will be analyzed if the reference space has high ventilation rates as compared to the required calculated from the formulas.

4.5.1 THERMAL COMFORT

The comfort category 1 is selected for the building with the upper temperature limit as 24.1˚C and lower temperature limits as -19.1 ˚C. Table 24 shows the comfort evaluation results for the above-mentioned evaluation period.

Table 24 Comfort and discomfort hours data

Comfort evaluation results		
	Comfort	**Discomfort**
n of hours	**997**	**3371**
% of hours	**23%**	**77%**

This means that the building has low comfort hours that are only 23% and very high discomfort hours that are 77%. As it exceeds the 6% so the thermal comfort level of the building is not acceptable. It is highly recommended to use better systems and stratigraphy to maintain the thermal comfort of the building.

4.5.2 INDOOR AIRQUALITY ASSESSMENT

In IAQ Assessment, the parameters that are to be added to find the IAQ for room 11 are the

- Comfort category = Category II
- Use of the building = Residential
- Building polluting level = Low (building where predominantly low emitting materials are used and materials and activities with emission of pollutants are limited)
- Conditioned net floor area = 21.49 m^2
- Conditioned net volume = 78.43 m^3
- No of occupants = 2
- Measured or designed ACH (air flow rate) = 0.15 1/h

Table 25 IAQ data

Design / Measured			Minimum for IAQ	
0.15	1/h	<	1.30	1/h

The airflow rate per area is calculated as 15.03 l/sm^2 and per person is 14 l/s, so the total airflow rate is 29.043 l/s. Table 25 shows the airflow rate is lower than the minimum flow rate that is 1.3 1/h so the IAQ in the building is not guaranteed. There is low ventilation so there are high pollutants in the building. The current building does not have good air quality for the occupants. In order to have the IAQ guaranteed in the building, it is compulsory to improve the ventilation system in the building. To reach above the minimum flow rate it is compulsory to have air flow rate more than 1.3 1/h to have IAQ comfort.

4.6 BACS ASSESSMENT

Table 26 illustrates the total controls that are implemented in the building and its BACS performance improvement index. Table 26 shows that the highest percentage reduction in the energy performance is by using the demand-based control for the distribution networks of the water temperature. In manual control, the water temperature is constant, and the excess heat is released. In the automatic control the energy is not wasted, and the energy performance is higher. Other controls can also be added to the system as they have an efficient effect.

Table 26 BACS summary

Sr.No	Building service	BACS Function	BACS Function in orignal state	BACS Function in real state	Primary energy need for the building in the orignal state-Ep0 (kW)	Primary energy need for the building with the function improvement implemented-Epi (kWh)	Percentage reduction of EP (%)
1	Heating control	Emisison control	No automatic control	Individual room control	24931	21505	14
2	Ventilation and air-conditioning	Supply air flow control at the room level	No automatic control	Occupancy based control	24512	21505	12
3	Heating control	Control of distribution network hot water temperature	No automatic control	Demand based control	60672	39860	34

5 CHAPTER 5: CONCLUSIONS

The purpose of TDS 2 is to enhance the Energy Performance certifications by integrating operational data. In previous chapters, we have observed the data collection to the results generation. It is evident that the results generated are based on tailored energy performance assessment. In this chapter, it will be explained how reliable the results are and how they can contribute towards the EPC schemas.

5.1 ANALYSIS OF RESULTS

I generated set of deliverables including BACS, IEQ, ECM assessments, and TEPA calibration and delivered it to TIMEPAC. These deliverables play a pivotal role in advancing energy performance certification. During the analyses, various challenges and enhancements have been identified. It's worth noting that each country or region maintains distinct rules and regulations pertaining to energy audits. The central aim of this research is to streamline and enhance the process of energy performance certification.

Table 27 Summary of deliverables

TEPA CALIBRATION	ECM ASSESSMENT	IEQ ASSESSMENT	BACS ASSESSMENT
• MBE= 2.6% • CV RMSE=28.8%	• Scenario 1 is the best economic scenario • Scenario 8 passess the NZEB rules of Italy	• Not Acceptable Thermal comfort= PDH>6% • IAQ in the building is not guranteed as volume flow rate <1.3 l/h (minimum for IAQ)	• Highest percentage reduction by control of distribution network water temperature that is 34% • Emission control=14 % • Supply air flow control at the room level=12%

Table 27 provides the abstract of the conclusions. In TEPA calibration, the MBE is under the limits and CV(RMSE) is under the hourly data limits (30%) but not the monthly data limits (15%) because of multiple reasons such as limits for the weekly data is not available, data range is for few weeks starting from beginning of the January to the beginning of the April and no smart monitoring. The total measured data is 42127 kWh while the total simulated data is 43212 kWh, that means that after the calibration the difference between data was reduced. It is compulsory to have the limits of mean biased error and CV(RMSE) for the weekly data for calibration process so that it eases the process of EPC. Scenario 1 is the best scenario for financial analysis. It has the lowest net present value 126.3 €/m^2 and DPP of the 10 years. It is also considered that if the scenario 8 is applied to the building, then the NPV and DPP are higher, but the building will be A4 and, following the Italian legislations, is a NZEB. In IEQ assessment, there are two domains as thermal comfort and indoor air quality. The number of the discomfort hours are 77% while the comfort hours are 23%. As the discomfort hours are greater than the 6% so the thermal comfort level is not acceptable. It is highly recommended to use better systems and stratigraphy to maintain the thermal comfort of the building. The indoor air quality of the building is not guaranteed as the design flow rate is 0.15 1/h and minimum required for the building is 1.3 1/h. The current building has not good air quality for the occupants. To reach above the minimum flow rate it is compulsory to have air flow rate more than 1.3 1/h to have IAQ comfort. By adding controls to the building, the efficiency of the system is improved. There is total three modifications in the control of systems such as by adding the emission control from no automatic to individual room control the percentage reduction of energy performance is 14%. The second control improvement is from no automatic control to occupancy-based control for the supply air that has the percentage reduction of 12%. The third control improvement is the change of control of distribution network of hot water temperature from no automatic to demand based that has impact of 34% reduction. This means that the third improvement has the potential to be applied to the building.

5.2 RELIABILITY OF RESULTS

The results are dependable as they have been generated in compliance with established standards. These results have been duly furnished to TIMEPAC. The pricing data for materials, labor, and other components has been sourced from the Prezzario della Regione Piemonte 2023 (PIEMONTE, 2023). The latter contains the prices for all the types of materials that are in Piemonte. It also includes the labor price per m^2. The software EC700 from Ediclima s.r.l. was utilized for calculating the outcomes such as primary energy consumption, temperature profile etc. considering various normative standards.

While adding the stratigraphy of some elements of the building, complete information was not provided of the material properties. The specific heat, dry and wet vapor pressure has been taken from the standards. The occupancy profile is also taken from the standards as such information is not provided. The specifications of the systems are taken from the data sheet in their websites that also defines the reliability of the results. Moreover, in order to check if the building is NZEB or not, all the criteria provided by the Italian legislations has been checked with EC700. While generating the results it is very important to have each value or equation that is according to the standards.

5.3 OBSTACLE DURING EPC

Following are the obstacles that are highlighted during the whole project:

1. **Incomplete data regarding the building stratigraphy:** There are some details that are not provided of the building stratigraphy. Some of the renovations were done in the building that were discovered during the site visit. The Revit file provided had less details and some of the standards were used to obtain parameters.
2. **Scarcity information regarding real occupancy**: In order to have precise energy audit, real occupancy details should be provided. As there was no such information regarding the occupancy, the standards values were used in the simulation. To fix this problem, smart systems should be integrated into the building that explains itself the occupancy.
3. **Insufficient system details**: Data provided was insufficient regarding the occupancy (factors, behaviors, and others), systems and stratigraphy.
4. **Standard limit values for weekly data**: As this research work is using the weekly primary energy consumption. In order to calibrate the data, the limits are provided for the hourly or monthly data but not for weekly by ASHRAE. It is important to understand such values in order to conduct the calibration of model.
5. **Others**: There are several other problems that are mentioned above in the deliverables that must be considered such as scenario 1 is considered as the best scenario but at the same time it doesn't comply with NZEB Italian standards

5.4 AID TOWARDS THE ENERGY PERFORMANCE SCHEMAS

As TIMEPAC encompasses various stages of EPC workflow such as generation, storage, analysis, and exploitation. In this research work, the generation phase is completed by performing an energy audit on the residential building in Torino. During the research work, all the result, stakeholders, methods, and tools involved are mentioned. The building data is stored in the database of TIMEPAC. By considering TDS 2, this data will be exploited and analysis to improve the EPC schemas. It is an iterative process so the betterment in the schema depends on the no of results generated regarding different types of buildings and countries. Multiple obstacles and are highlighted in the research work that will be solved in the future to avoid the problems in EPC. Figure 42 explains the whole process by which the research will aid towards the energy performance certifications.

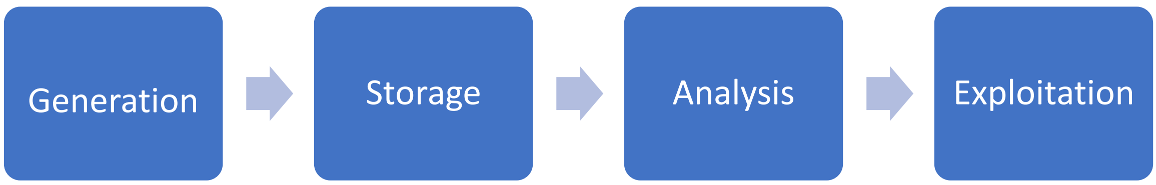


Figure 42 EPC workflow

5.5 FUTURE RECOMMENDATIONS

This research carries significant implications for the future of the energy performance certification process. The energy audit data should be obtained with the higher precision. The auditors must be skilled and educated regarding the EPCs to increase the effectiveness of the EPC schemas. Standardization of tools and methodologies across all project partners is equally crucial, to ensure uniformity in processes. It is important at the same moment to make the system of EPC generation greener by adding more features that are environmentally friendly. When there is a registration and renting of the buildings, there should be strict legislation of obtaining the EPC. The owners should be facilitated about the process of a EPC generation. To elevate the quality of EPC, education and awareness initiatives should target not only auditors but also occupants. In the future, a multiple array of buildings will undergo audits at various levels, to generate significant results. The results will be stored in TIMEPAC data base and later will be analysed. This operational data integration will play an important role in enhancement of Energy Performance Certification schemas.

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ANNEX 1

Heat Pump specifications

Technical data

Model		SPC 200	SPC 300	SPC 300 S
Energy rating		A+	A+	A+
Load profile		L	XL	XL
Capacity	lt	215	270	260
Water heating energy efficiency ÿwh	%	152	161	129
Heating time (1)	h	5	7	7
Average heat pump power (1)	kW	1.7	1.7	1.7
Average electrical power absorbed (1)	W	500	500	500
Power of the integrative electrical resistance	kW	1.8	1.8	1.8
Maximum operating pressure	Cafe	10	10	10
Supply voltage	V-Hz	230-50	230-50	230-50
SPC 300 S exchange surface	m2	-	-	1
DHW quantity supplied at 40°C (cold water at 15°C)(1)	lt	275	378	383
Heat dispersions	kWh/24h	0.73	0.67	0.75
Pes (2) (3)	W	25	35	32
Air flow (ÿP=25 Pa)	m3/h	320	320	320
Air pressure available at the fan	Pa	50	50	50
Maximum water temperature with heat pump	°C	65	65	65
Maximum water temperature with integration	°C	70	70	70
Min/max air temperature	°C	-5/35	-5/35	-5/35
Minimum volume of the installation room (without air ducting)	m3	30	30	30
R134a refrigerant fluid quantity	kg	1.45	1.45	1.45
CO2 equivalent R134a	t	2.07	2.07	2.07
Indoor sound power level, LWA	dB(A)	57	57	57
Empty weight	kg	[illegible]	105	123
Degree of protection		IPX4	IPX4	IPX4

Performance data according to the indications of UNI TS 11300-4

	COP (4)				Pt [W] (4)			
T air (°C)	7	15	20	35	7	15	20	35
SPC 200	2.73	3.34	3.72	4.80	1327	1536	1704	2532
SPC 300	2.93	3.50	3.94	5.23	1422	1645	1825	2712
SPC 300 S	2.68	3.29	3.60	4.78	1328	1537	1705	2534

(1) Value for domestic water heating from 15°C to 51°C with an air inlet temperature of 15°C.
(2) Value obtained with an air temperature of 15°C and a water inlet temperature of 10°C, according to EN 16147 (3)
Power absorbed with stabilized speed (4)
Value obtained with a water temperature produced at 55°C

Accessory

	Description	Code
	Single vertical air connection kit with outlet Ø 200 mm (order 2 pieces to have the complete kit)	A7213894

ANNEX 2

PV panel specifiations

Silver Plus

S610SPP
S612SPP

solsonica
Chiara come il sole

English

BEHAVIOUR UNDER STANDARD TEST CONDITIONS (1000 W/M² - 25°C)

Cells	Product code	Pmax (W)	Voc (V)	Vmp (V)	Isc (A)	Imp (A)	Eff. (%)
60	S610SPP-235	235	36.61	29.17	8.61	8.05	14.16
	S610SPP-240	240	36.85	29.51	8.65	8.13	14.46
	S610SPP-245	245	37.17	29.76	8.77	8.23	14.76
	S610SPP-250	250	37.54	30.03	8.83	8.32	15.06
	S610SPP-255	255	37.68	30.19	8.96	8.44	15.36
	S610SPP-260	260	37.82	30.35	9.08	8.55	15.66
72	S612SPP-285	285	44.40	35.37	8.61	8.05	14.43
	S612SPP-290	290	44.53	35.65	8.65	8.13	14.68
	S612SPP-295	295	44.76	35.84	8.77	8.23	14.94
	S612SPP-300	300	45.05	36.04	8.83	8.32	15.19

For aesthetic features refer to the picture.

Mechanical characteristics	S610SPP	S612SPP
Cell type	Polycrystalline silicon, 3 bus bar	Polycrystalline silicon, 3 bus bar
Cell dimensions (mm)	156x156	156x156
Module dimensions LxWxH (mm)	1663x998x35	1979x998x35
External frame	Aluminium	Aluminium
Weight (Kg)	21.4	26
Junction box	Protection Class IP65	Protection Class IP65
By-pass diodes	3	3
Cables	Wire section 4 mm², Length 2.00 m (MC4)	Wire section 4 mm², Length 2.30 m (MC4)
Glass	Temperated ARC glass 4 mm	Temperated ARC glass 4 mm

Other electrical characteristics	S610SPP	S612SPP
NOCT (°C)	43.2	43.2
Thermal variation for short circuit current (%/°C)*	0.042	0.042
Thermal variation for vacuum voltage (%/°C)	-0.335	-0.335
Thermal variation for maximum power (%/°C)*	-0.454	-0.454
Performance tolerance (W)	-0/+4	-0/+4
Max. system voltage (V)	1000	1000

*Measured by Fraunhofer ISE

STRUCTURE

- Protective ARC (Anti Reflective Coating) glass for maximum performance, thickness 4 mm
- Cells encapsulated in high quality EVA (ethylene vinyl acetate)
- High performance impermeable backsheet

Release 5.1